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THE TRANSACTIONS

OF THE

Canadian Mining Institute

(With which is incorporated the Transactions of the Mining Society of Nova Scotia)

1918

EDITED BY THE SECRETARY

VOLUME XXI

"The Institute as a body shall not be responsible for the statements and opinions advanced in the papers which may be read or in the discussions which may take place at its meetings."—*By-Laws, Par. 48.*

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Mr. D. B. Dowling,
President of the Canadian Mining Institute,
March 1918 to March 1919.

REPORT OF COUNCIL AND FINANCIAL STATEMENT FOR THE YEAR 1917

In submitting its Annual Report upon the work and business of the Institute for the year ending December 31, 1917, the Council is gratified to record that the affairs of the Institute are in a very satisfactory condition. Despite the fact that there has been a considerable loss of revenue consequent on the exemption from fees of members serving with the colours, the financial position of the Institute is unimpaired. This is owing chiefly to the efforts of the 'Membership Committee,' appointed by Council, who succeeded in influencing a large increase in the membership during the year. In this connection thanks are due in particular to Mr. E. E. Campbell, Mr. J. E. Murphy, Mr. J. T. Stirling, Mr. J. H. Stovel, and Mr. Geo. Wilkinson for their zealous and devoted labours. The publications of the Institute were also considerably greater in bulk than in any previous year.

National Service

In addition to its routine activities, the Institute during the past year has again been afforded the privilege of co-operating with governmental departments at Ottawa in the carrying out of measures for the prosecution of the war, and also of measures designed to prepare the industries of the country for effective adaptation to the conditions which are likely to confront them upon the restoration of peace. In the former connection, the Institute rendered assistance to the Department of Militia and Defence by recommending, or endorsing, the applications of mining engineers for commissions as tunnelling officers, while the Institute's services were also requisitioned by the Military Service Branch of the Department of Justice. In regard to preparations for peace, an important part was taken by the Institute, in co-operation with the Canadian Society of Civil Engineers and other national engineering and technical organizations, in the work, undertaken at the request of the Honorary Advisory Council for Scientific and Industrial Research, of

distributing and securing replies to a questionnaire addressed by the Research Council to some twenty thousand industrialists throughout the country. The purpose of this questionnaire was that the Research Council might be informed concerning the research requirements and problems of Canadian industry, and, as it was desired that so far as possible the distribution should take the form of an individual canvass of the firms and corporations listed, the task imposed was by no means a light one. The readiness and zeal displayed by members of the Institute in undertaking this service, which was of an exacting nature, is deserving of the highest praise. The work also occupied much of the time of the Secretary during the greater part of the year. It should be mentioned further that the President of the Institute acted as field organizer for the Central Directing Committee of the volunteer organizations, and in this capacity made a complete tour of the country, visiting each Province in turn. The work in the Province of Alberta was under the direct charge of Mr. J. T. Stirling, Secretary of the Rocky Mountain Branch of the Institute. A census of the mining men of the Dominion was also taken by the Institute for the information of the authorities.

Canadian Department of Mines

For many years past the Institute has consistently urged that the national importance of the mining industry of the country entitled it to representation in the Dominion Cabinet by a Minister charged solely with the administration of the Department of Mines. Ever since the establishment of the Department, however, the Portfolio of Mines has been entrusted as a secondary honour to a member of the Cabinet holding office either as Minister of Inland Revenue or as Secretary of State—neither of which Departments has any relation with the Department of Mines. Having regard to the proposed establishment of an Imperial Bureau of Mines in Great Britain, to correlate the information concerning the mineral resources of the British territories with a view to more effective development of the metal trade within the Empire, it is now more than ever

desirable that the scope and activities of the Dominion Department of Mines should be increased. The Council again made representations to this effect to the Prime Minister last April, but without result up to the present time. It is, however, a matter of congratulation that in the present Cabinet the Department of Mines should be represented, though only as a secondary interest, by the Hon. Martin Burrell, who is keenly alive to the national importance of the mining industry, is in sympathy with efforts to promote its development and prosperity, and whose capacity as an administrator is widely recognized.

Removal of Headquarters

Almost continuously since the foundation of the Institute its library and general offices have been established in one of the large hotels in the city of Montreal. The main consideration determining this choice of location was the convenience of members visiting headquarters, as until recently no suitable offices centrally situated were obtainable in the uptown section of the city. The disability having been removed by the erection of a large modern office building within a short distance of the hotels and railway terminals, the Council decided that a renewal of the lease of the premises at the Ritz-Carlton Hotel, on less favourable terms than before, need not be considered. In consequence a removal was made to the Drummond Building, 511 St. Catherine Street, Montreal, on December 1st. The present quarters are more commodious than those formerly occupied, are most centrally situated, and will, it is believed, admirably satisfy the requirements of the Institute for some time to come.

Meetings

The Nineteenth Annual General Meeting of the Institute was held in Montreal on March 5th, 6th, and 7th. The attendance was large. A specially interesting event was the presentation of the gold medal of the Mining and Metallurgical Society of America to Mr. E. P. Mathewson. The presentation was made by Mr. Ingalls, President of the Society, who was supported

by a number of eminent mining engineers from the United States forming the Society's delegation. The Society's courteous intimation that it would be glad to be afforded the opportunity of presenting the medal to Mr. Matthewson at the Annual Meeting of the Institute, in recognition of his Canadian nationality and as a compliment to the Institute, was greatly appreciated by the Council. Meetings, at which papers were presented and discussed, were also held during the year at Nelson, Vancouver, Merritt, and Princeton, B.C., under the auspices of the Western Branch; at Calgary, under the auspices of the Rocky Mountain Branch; and at Montreal, under the auspices of the Montreal Branch. The Toronto Branch has continued to hold regular fortnightly meetings except during the summer months.

Publications

The publications of the Institute during 1917 comprised twelve numbers of the Monthly Bulletin, and Vol. XX of the Transactions; the latter, it is expected, will be ready for distribution early in February. In point of bulk the publications of the Institute have increased steadily during the past few years, and in 1917 all previous attainments in this respect were exceeded. The Bulletin has been specially appreciated by the members on military duty overseas, for its utility in keeping them informed concerning the work of the Institute and the progress of mining in Canada, in which they continue to display the keenest interest. The Secretary desires to acknowledge with gratitude the assistance rendered him in the editing of manuscripts by Dr. Alfred Stansfield and Professor J. W. Bell. Thanks are also due to those members who contributed special articles or who acted as special contributors to the Bulletin, and especially to Mr. C. V. Corless, Mr. T. W. Gibson, Mr. F. W. Gray, Mr. R. P. D. Graham, Mr. W. J. Dick, and Mr. J. T. Stirling. Appreciation of the kindness of the *Engineering and Mining Journal* in continuing to contribute monthly reviews of the metal markets to the Bulletin throughout the year is also most cordially expressed. The Institute has now enjoyed the advantage of this gratuitous service for three years.

Library

In addition to the accessions to the library, during the year, of Government reports, technical periodicals, and other exchanges, a number of books sent by publishers for review were added to the shelves. The library was further enriched by the generous donation by Mr. E. P. Mathewson of a number of useful as well as rare and valuable volumes, including a first edition of Agricola's "De Re Metallica," and "Petus on Metals."

Members on Military Service

The total number of members on military service is now 125. Of these 14 joined the Allied forces since January 1st, 1917. In all eleven members have given their lives in the cause of Freedom and Right—two in 1915, three in 1916, and six in 1917. The names of the following members on military service prior to January 1st, 1917, were omitted from the list published in the Council's Report of last year: Edward Ashburner, O. S. Batchelor, Prof. John Cadman, J. L. Coulson, W. F. Gowans, J. G. McMillan, Frank Nicholls, G. M. Ponton (home service with Imperial Munitions Board), and Alex. H. Smith.

The following have joined the colours since January 1st, 1917; V. H. Emery, S. C. Ells, Stanley Gray, Wm. Hutchison, W. E. Lawson, S. C. McLean, Boyd Magee, C. O. Noble, J. R. Rutherford, H. L. Scott, A. L. Sharp, Sydney Smith (U.S. Army), A. W. H. Smith, and N. A. Stockett (U.S. Army).

It must be a matter of pride to the Institute that so large a proportion of those of its members serving with the colours have won military decorations for distinguished and gallant service. The splendid achievements of the Canadian Tunnelling Units, officered principally by members of the Institute, have in particular commanded our admiration, and their great deeds have on more than one occasion during the past year been commended in the despatches of the Commander-in-Chief of the British Armies on the Western Front.

MEMBERSHIP

The total membership at December 31st, 1917, was 1,118, as compared with 1,066 at December 31st, 1916. The increase in membership is attributable mainly to the efforts put forward by a Committee appointed by Council, under the Chairmanship of Mr. W. G. Segsworth, to co-operate with the Secretary in this regard.

At the Annual Meeting in Montreal Mr. H. C. Hoover was, with the unanimous consent of the members present, elected an honorary member of the Institute, in recognition of his noble work as organizer and chairman of the Belgium Relief Commission.

The accessions during the year are classified as follows:

Ex-officio Members	1
Members	116*
Associate Members	19*
Student Members	1
Honorary Members	1
	138

The losses by death, resignation, and removal were as follows:

Deaths	15
Resignations	28
Removals	43
	86

* Thirty members and four associate members elected in December, 1917, were given the privilege of accepting election from January 1st, 1918.

The loss by death of the following members is recorded with deep regret:

A. C. Bailey, Wm. Blakemore, David H. Browne, D. D. Cairnes, Lieut. C. St. G. Campbell† (in action), C. W. Drysdale, J. S. Fleming (in action), Ernest Gheur, Capt. G. G. Gibbins (in action), A. M. Hay, Col. T. C. Irving (in action), Lieut. O. E. LeRoy (in action), Lieut. C. P. McDougall (in action), Donald McKay, and A. P. Turner.

The following members resigned their membership during the year:

H. G. S. Anderson, A. M. Baker, A. J. Beaudette, F. J. Bourne, J. T. Burchell, S. R. Cragg, J. G. Cross, Nelson C. Dale, G. G. Dobbs, R. Feldenheimer, B. E. Fernow, T. W. Harpell, C. S. Horton, T. R. Jackson, Geo. Johns, J. A. Lewisohn, Jas. McGregor, A. L. McKillop, C. J. Murphy, N. J. Norton, J. G. Powell, P. Rochussen, Thos. E. Smith, J. A. Swanson, J. R. Thoenen, J. Vallance, J. A. Whittier, and F. G. Whitworth.

The following table enables a comparison to be made between the membership returns of 1916 and 1917:

	Dec. 31, 1916	Dec. 31, 1917
Patrons	6	5
Corresponding members	16	15
Honorary members	5	6
Ex-officio members	50	48
Life members	10	10
Members	827	894
Associate members	127	122
Student members	6	5
Affiliated student members	19	13
	1,066	1,118

ARTHUR A. COLE,
President.

H. MORTIMER-LAMB,
Secretary.

† Presumed.

TREASURER'S REPORT

RECEIPTS AND DISBURSEMENTS FOR THE YEAR ENDED 31ST DEC., 1917

Receipts

Cash in Bank 1st January, 1917			$5,701.10
Subscriptions:			
Annual		$6,985.00	
Less: Paid in advance of 1917		110.00	
		6,875.00	
Students		19.00	
Advance		100.00	
Arrears		1,450.00	
			8,440.00
Publications:			
Sales	305.47		
Advertisements	1,618.83		
Binding	226.50		
Index	60.00		
			2,210.80
Miscellaneous:			
Dominion Government Grant	3,000.00		
Bank Interest	155.86		
Interest on Investments	872.50		
Sale of Buttons	1.00		4,029.36
			$20,385.26

Disbursements

Publications:			
Printing and Distributing	$5,147.30		
Editors' Salary	1,600.00		
		$6,747.30	
Meetings:			
Annual		159.33	
Secretary's Office:			
Salaries	4,565.00		
Less: Chargeable to Publications	1,600.00		
		2,965.00	
Rent, Rates and Taxes		1,100.00	
Telephone and Telegrams		148.63	
Postages		356.22	
Express		16.68	
Printing and Stationery		304.31	
Travelling Expenses		114.95	
General Expenses (Auditors' Charges, Bank Charges, Removal Expenses, Insurance, etc.)		322.21	
		$12,234.63	
Permanent Fund:			
Furniture		254.18	
Library		2.20	
Dominion of Canada War Bonds		2,903.89	
Reserve to Complete Vol. XX		3,000.00	
Balance Jan. 1st, 1917		1,990.36	
			$20,385.26

H. MORTIMER-LAMB, Secretary-Treasurer.

Audited and Certified Correct,
(Signed) P. S. Ross & Sons,
Chartered Accountants.

Montreal, January 11th, 1918.

PRESIDENTIAL ADDRESS

By Arthur A. Cole

(Twentieth Annual Meeting, Montreal, March, 1918)

This year the Canadian Mining Institute passes the twentieth mile-post in its career; and notwithstanding the fact that this is now the fourth year of the world-war, that "Great Calamity," the growth in influence and usefulness of this Institute has suffered no check, but rather has increased steadily. Every Canadian worthy of the name is now bending his energies to help win the war; and, in order to justify its existence at the present time, every society must be able to show that it is wholeheartedly working towards the same goal. At the outbreak of hostilities many of our members were among the foremost to volunteer for overseas military service, and long before the Canadian Military Service Act was passed practically every member who was physically fit and of military age was in khaki. Most naturally these comprised the very pick of our membership and we are more than proud of the enviable record they are making at the front. Much of their work must necessarily be of a destructive nature; but those at home must participate in a great constructive task. While we are assisting in every way possible in winning the war, we must also be preparing to aid in solving after-the-war problems. Lloyd George says: "Economic conditions at the end of the war will be in the highest degree difficult, owing to the diversion of human effort to warlike pursuits. There must follow a world-shortage of raw materials which will increase the longer the war lasts."

Canada, with her vast resources of raw materials, will thus be in a specially favoured position among the nations. The appeal for preparedness is most urgently applicable to the members of the Canadian Mining Institute, as representatives of the great basic industry that must be responsible for the making of many of these raw materials available for our industries and commerce. In order to do that, it seems to me that our way is clear if we follow the trend of our national development towards greater independence and self-reliance.

Political Self-Reliance.—At the session of the Imperial War Conference held in London on April 16th, 1917, and attended by the Prime Ministers of the Overseas' Dominions, a resolution was passed which refers to the future status of the self-governing Dominions. The resolution says that any future settlement that is to come must be "based upon a full recognition of the Dominions as autonomous nations of an Imperial Commonwealth." This does not necessarily mean a tendency towards autonomous government apart from the British Empire. Canada's actions since the war began speak more clearly for her loyalty to the Empire than any verbal protestations ever can. It is the evolution of a more perfect autonomous nationality as a unit in what General Smuts has aptly termed the "British Commonwealth of Nations."

Financial Self-Reliance.—Before 1914 Canada was essentially a borrowing nation. We were building railways, developing our industries and exploiting our natural resources at an enormous rate, and in order to do so we were borrowing the needed capital from other countries, chiefly from Great Britain. For the last six years previous to the war our yearly borrowings averaged $200,000,000, and our annual interest charges had reached $175,000,000. We also had a large adverse trade balance. With the opening of hostilities all borrowings from the Mother Country were cut off, and we have been thrown on our own resources. For a time the outlook was very black, but the demand for war supplies, particularly from Great Britain, taxed many of our industries to their utmost, and in many cases expansions had to be made to meet the unprecedented demands. Eventually, the Government had to appeal to the people of Canada themselves for the first war loan and the gratifying result was that the loan was over-subscribed 100 per cent. The second and third war loans met with a like response, but Canada's crowning financial effort was the Victory Loan of last December, when on a call for $150,000,000 a total of $417,000,000 was received from over 800,000 subscribers. Not only does this show the loyalty of Canadians in supporting the carrying on of the war, but indicates the great present prosperity of the country.

Our unfavourable trade balance with the Mother Country

has been changed to a rapidly increasing favourable trade balance which in 1917 passed $400,000,000. This balance is now being used to wipe out some of our foreign borrowings or to transfer them to this country. As a result of this movement our large outside interest payments are rapidly being reduced and the interest paid out at home is correspondingly increased. Our financial standing is consequently enormously strengthened. Canada is rapidly changing from a borrowing nation to one that is self-supporting, showing the strong current in the direction of financial self-reliance.

Industrial Self-Reliance.—Our general industrial and commercial developments are so clearly related to and dependent on the mining, metallurgical, and chemical industries that it is next to impossible to draw a hard and fast line between them. Hence it is better to consider them together.

In 1915, the mining, smelting and related industries of Canada employed 104,425 men and yielded products of a value of $265,046,000. In addition, and directly following this production, 50,393 men were employed in further manufacturing these products, to which was given thereby an added value of $103,912,000. Thus, of a total of 2,723,000 wage-earners in Canada, one-ninth are employed in the mining and dependent industries. As a further evidence of the importance of the mineral industry it may be noted that in 1915 the tonnage supplied to the railways of Canada by the different industries was:

Products of Mines	37.89%
Products of Agriculture	18.79%
Products of Forests	16.03%
Manufactures	14.76%

The part that the mining industry has played in connection with the development of the country has been great in the past, but it must be of still greater importance in the future if our record is to be one of continued national expansion and progress. The members of this Institute are to a large extent responsible for the production of the raw materials that form the basis for our metal industries and that enter largely into much of our gen-

eral manufacturing. In order to utilize to the best advantage our natural resources, it is first necessary that we should have an inventory of them. Such an inventory would prove an effective guide to industrial possibilities, and would probably reveal economic sources of raw materials within our borders which are not at present being developed. We will thus be laying a broader and firmer foundation on which to build the superstructure of our industrial and commercial activities, giving them a greater degree of national independence.

In a consideration of our international commerce we find that our imports of crude mineral products are only slightly in excess of a similar grade of exports, nevertheless much of our exports of raw materials should be more highly manufactured before leaving the country. Moreover, a great quantity of manufactured products is imported, much of which is actually made of our own raw materials.

The question is: How can we best assist in the attainment of a greater *Industrial Independence and Self-Reliance?*

Certain branches of the mineral industry are well developed and are expanding; others are in their infancy; while in other lines we are far from being self-supporting. The demands of the war have stimulated certain branches of our metal industry to an extent undreamed of a few years ago. Iron and steel are most noteworthy examples. This could not be otherwise when we consider that through the Imperial Munitions Board orders have been placed in Canada aggregating $1,100,000,000 for munitions, and on these orders the sum of $875,000,000 has already been expended. Among other things, Canada has machined 53,000,000 shells, and munitions are now being made on a large scale for the United States. Between 500 and 600 plants in the country are employing from 250,000 to 300,000 workers, including as many as 35,000 women at one time. How can we arrange that, when the war orders cease, the industry will not fall back. In the expansion of this industry for war work a large number of electric furnaces for the production of shell steel have been constructed. This steel is largely made from steel turnings produced in the manufacture of shells, but Dr. Alfred Stansfield thinks "that before long we

shall be using the electric furnace, as in Sweden, for the production of pig iron and steel from our native ores, and shall thus add materially to the value of the iron and steel trade, which is always a basic one in any industrial country."

Among the metals now for the first time being produced in the refined form in Canada may be mentioned, copper, zinc and magnesium. Works near Montreal and Toronto have been established or enlarged for the working up of brass and copper so that in future the Canadian manufacturers should be better "able to obtain their requirements in this country and be less dependent on importing their supplies from abroad." In the case of magnesium the outlook is not so rosy, but a possible outlet for this metal is in light alloys suitable for use in aeroplane construction. Turning to the precious metals, the silver producers seem well pleased with the present status of the metal, and are satisfied for the future to let the law of supply and demand take its course, the general belief being that the world-shortage is bound to stiffen up the price. With gold, however, the circumstances are altogether different. Gold has been adopted as the standard of value by all the leading nations of the world. Being the standard of exchange, its nominal value remains stationary, but if we judge it by its purchasing value of such commodities as wheat we find that in the last five years it has depreciated about 50%. This has started an agitation among some people for the discontinuance of gold mining while this condition holds, and others go further and contend that gold is a non-essential, and that gold mining therefore should be discontinued for the duration of the war. I am most emphatically opposed to this view. At the present time we are fortunate in having favourable trade balances with both Great Britain and the United States, but this is the first time in our history that such has been our happy lot. We need a surplus of gold so as to be able to liquidate any adverse trade balance, and we also need more gold than we have at present in order to increase our reserve somewhat in the proportion in which we are increasing our national indebtedness. This gold reserve forms the foundation on which we build the structure of our national credit. In this connection an excerpt from the

recent annual report of the General Manager of the Canadian Bank of Commerce is of interest:

"After the United States came into the war the shipments of gold from Great Britain to that country ceased, and a slight adverse movement set in; in order, therefore, to conserve its holdings and to prevent gold from reaching the enemy, the United States Government placed an embargo on exports of the metal. Upon representations being made at Washington, however, through the Canadian Bankers' Association, as to the unfairness of enforcing the embargo against us, the release to Canada of a certain amount of gold was arranged for. While this will, doubtless, aid in the stabilizing of the exchange between the two countries we feel that it is important that the underlying gold reserves of Canada should be increased to correspond with the great increase in the liabilities of the Canadian banks resulting from war activities. To this end we consider that our endeavours should be directed, and we believe also that the Government of Canada should place an embargo on the export of gold produced in Canada, and see that it is made available for this purpose."

Another point that should not be overlooked is the fact that the gold mines have been hard hit by recruiting; and in many cases a mere handful of workers are keeping the mines in operation. If these mines are encouraged to continue working during the war they will form foci where industrial activity can be quickly expanded to meet after-the-war readjustment of labour conditions.

In the consideration of deficiencies among our natural resources, the greatest is assuredly our lack of fuel in Central Canada. Our coal deposits of the East and West represent over 17% of the world's reserve of coal, but our production is comparatively small, and we import more than we produce. We are entirely dependent on the United States for these imports, and if for any reason this source of supply should be cut off or even restricted, the results in Central Canada would be proportionately disastrous. The further development of hydro-electric power will replace a large amount of coal now used for the generation of power. To take the place, in part at

least, of the imported coal now used for heating purposes, we have a possible solution in the briquetting or other preparation of the low-grade fuels of Manitoba, Saskatchewan, and Alberta, while in the East we have millions of tons of excellent peat located in bogs adjacent to our principal industrial centres awaiting commercial development.

In carrying out any plans looking towards the development of our metal industries along lines of greater independence and self-reliance, our principal work must be carried on through our governmental departments, either Federal or Provincial. The Canadian Mining Institute has recently presented to the Prime Minister a memorandum containing certain constructive suggestions along these very lines. One of the chief suggestions was the immediate consolidation and strengthening of the Department of Mines. If this is done, much of the past and present dissipation of funds and energy can be avoided through non-duplication of effort by different branches of the Civil Service and Commissions. If the Department of Mines were strengthened and extended to a degree commensurate with the importance of the mineral industry in Canada, I am firmly convinced that a Minister of Mines charged with the work of this Department and giving his undivided attention to it would find that he had one of the most important portfolios of the Cabinet, and worthy of the best work of the biggest man mentally that the Government of Canada can select.

If, however, the Department of Mines is to be strengthened, the remuneration of the technical members of the staff must materially be raised. If this is not done the best men will leave the Government service to engage in better paid employment elsewhere. These remarks are equally applicable to some of our Provincial Bureaux. An illustration of the point it is desired to make may be found in a recent advertisement issued by the Civil Service Commission of Canada, in which applications were invited from candidates qualified to fill the following positions:

1.—A legal officer to be appointed to one of the departments in Subdivision A of the First Division, at an initial salary of $3,300 per annum. Candidates must be at least twenty-eight years of age, must have had a few years' practical experience in law, and must possess a good general education.

2.—A Chemist for the Fuel Testing Division of the Mines Branch of the Department of Mines, Subdivision A of the Second Division, initial salary $1,600 per annum. Candidates must have a thorough training in Chemistry and Physics and hold a degree from a recognized university, should have proved their ability to undertake original research, and have had subsequent experience in practical Chemistry. They must be thoroughly familiar with the methods of gas analysis where great accuracy is required, and must be capable of testing the methods and calibrating the apparatus used in their work.

The qualifications required of the Chemist are such as would entitle him to a Ph.D. degree at any of the best Universities on the Continent. The absurdity of the discrimination thus instanced is further emphasized when we know that in the Mines Branch only the Director receives a higher salary than that mentioned in the above advertisement as the amount to be paid at the start to the legal officer, whose duties could quite readily be performed by any mediocre country lawyer, or even by a clerk who had had a few years' experience in a lawyer's office.

The work of the Department of Mines should be extended so that not only would it deal with the winning and manufacture of our minerals and mineral products, but would embrace a study of markets in close co-operation with the Department of Trade and Commerce. Closer co-operation between the Department of Mines and the Provincial Bureaux of Mines should be encouraged also.

In recent years Germany's industrial progress and trade expansion has been due in large measure to the cartel system, which is a combination fostered by the Government to help small and large producers in the marketing of their products and also in the purchasing of supplies. If our mineral products were handled in some such co-operative manner great savings would result, and we would have some chance of thwarting the designs of the German Metal Trust which, when war broke out, all but controlled the metal markets of the world. Co-operation among producers with the sanction and support of the Government should be a watchword within the industry.

The Activities of the Institute.—The Canadian Mining Institute, through its membership from the Atlantic to the Pacific, can and is ready to aid the Government in every way possible, either directly or indirectly, through co-operation with

the Department of Mines in carrying out any constructive work for the benefit of the industry which in the end will benefit the country as a whole.

Last year the Canadian Mining Institute, in co-operation with several other societies, undertook the distribution of a questionnaire for the Honorary Advisory Council for Scientific and Industrial Research, for the purpose of obtaining an inventory of the research facilities existing in Canada. This co-operative effort was a start in the right direction; and it may confidently be asserted that the Institute would welcome other similar opportunities to be of national service.

There is a movement on the part of a few engineers to try to combine within a single society all engineers, no matter to what branch of engineering they may belong. This is a decidedly retrograde movement and is foredoomed to failure, as it is working directly contrary to the natural tendency of our national progress towards more independent development and self-reliance. The different branches of engineering have become so specialized that, as soon as a branch becomes strong enough, it is bound to form an independent self-supporting society. As a pioneer along these lines, we welcome such development, feeling that in this way the best results can be obtained. During times of stress when concerted action is necessary, co-operation is easily obtained between the executives of the different engineering societies.

Notwithstanding the large number of our members serving with the colours, the work and influence of the Institute is increasing and this is being more and more recognized by the Government and the country at large.

As to the war-work that is being accomplished by our individual members—and practically every one is engaged in it to a greater or less extent—I wish to mention particularly the excellent work of some of our members in the training of disabled returned soldiers for useful occupations. The results obtained in numerous instances are little short of marvellous.

The Future.—Difficult though the crisis through which the world is now passing may appear, our faith never wavers in the justice of our cause nor in its ultimate triumph. Our belief in

the future of Canada is steadfast. If we, as the representatives of one of the great basic industries of the country, perform our duty faithfully and fearlessly we may face the future calmly and with confidence, and in the knowledge that the all-wise Providence has bountifully endowed our beloved Canada.

DISCUSSION

DR. W. L. GOODWIN: In complimenting the President on the scholarly character and breadth and suggestiveness of the address he has just read, I wish to speak a few words on the paragraph headed "Industrial Self-Reliance." It is characteristic of the people of which we form a part to push this principle of self-reliance to an extreme of individualism. This is an age and time in the history of the world when the necessity of getting together in order to carry on great projects is being impressed upon us at every point, and I therefore beg to differ somewhat with him—although I do not think I need differ very much—in the emphasis that he has placed on that point of self-reliance. A great deal of the success with which Canada will pursue her development during the next few years will depend upon wise planning and the co-operation of the best minds and the best energy which we have in the country. A great deal will depend upon the course which the learned societies take in carrying on their activities, and my own opinion is that we shall not be able properly to impress our legislators, properly to educate the sentiment of the people of our country, unless we formulate and carry to a successful outcome some plan of getting together, instead of emphasizing individualism. And I therefore beg to suggest that one step in this direction would be the getting together of all the scientific and learned societies in Canada—not in the way which has been foreshadowed by the recent act of one of our sister societies; not by the process by which the lion lays down with the lamb inside of it; but in another way. I don't think, however, we should quarrel with the Canadian Society of Civil Engineers for changing its name—why, bless my soul, every married man in this room has demanded of the lady who became his wife that

she should change her name—and we have come to the conclusion that a rose by any other name smells just as sweet. Why then should we quarrel with the Canadian Society of Civil Engineers for that? We may quarrel with them if they try to swallow us —that is a different thing; but my suggestion is that in order to make ourselves strong—I mean by ourselves the scientific forces of this country—to make ourselves strong for a number of great purposes, such for example as, in the first place, to force our Dominion Government and the Provincial Governments, as far as it is necessary, to begin at once with a comprehensive and wide-flung system of industrial education, and to forward our advocacy of such obvious measures as the improvement of our Dominion Department of Mines and other necessary reforms. Much can be accomplished in the direction of national services by the concerted and united efforts of the scientific brains of the country, irrespective of whether they are mining engineers or chemists or civil engineers or what not. It is the getting together we need. The whole history of this struggle of the last four years has emphasized that point. Our enemies are strong because very early they seized upon that principle, in all their industrial developments, of acting unitedly; saving waste by acting unitedly. They are strong because of that, and our chief weakness has been the excessive development of individualism. And that will continue to be our weakness unless we get the other idea. I would suggest something like this—that the Canadian Mining Institute should take the initiative in bringing about some kind of confederation of the learned scientific societies, the Canadian Society of Civil Engineers, the Society of Chemical Industry, and all the others. Such a confederation would serve a great purpose. Meetings could be held, once every three years, or as often as necessary, for the discussion of questions of national importance and for planning together in the public interest. In that way, acting unitedly, we could so influence public opinion and impress ourselves on the authorities as to ensure that measures for the development of the country should be of the most effective character. I cannot see how we can make this impression and bring about these results unless we act together,

and the advantages of such a course seem so self-evident as to require no argument.

MR. B. NEILLY: I would be inclined to align myself with the President in his appeal for self-reliance, and if I were to offer any criticism it would be mild and with the idea that to self-reliance should be added self-knowledge and self-respect. By that I mean individuals should make greater efforts to obtain a true perspective and a true conception of the relative importance of the mining industry to the other industries of Canada. This is well illustrated, sir, in the circular you quoted emanating from the Commission having to do with the engaging of civil servants. I think the lack of appreciation of the value of scientific knowledge displayed in that advertisement is attributable not only to the ignorance of those constituting the Board, but to apathy or indifference on the part of those who should have the best interests of the industry at heart. This indifference is only too apparent. You have mentioned that almost one-ninth of all men working in Canada are engaged in the mining industry, and you have alluded to the fact that of all the freight handled by the railways 37% or 38% represents the products of the mine, and that in the United States the proportion is over 50%; and we accept those statements as a matter of course. But when, for example, the Railway Board intimated its intention to increase railway rates the grain-growers and farmers from the West headed for Ottawa to protest, and the Canadian Manufacturers' Association swelled the chorus; but although the mining industry contributed freight equal to the combined tonnage of the other industries, there was not one word said about the effect of the increase in rates on the mining and allied interests. That this should have been so is our own fault within certain bounds; and that is why we should have a greater self-knowledge and should make it our business to educate the general public in Canada to a more adequate understanding and appreciation of the national importance of the mining industry.

MR. J. J. HARPELL: There is very little difference between the views expressed by the President in his Address and those

of Dr. Goodwin. It is a fundamental fact that a nation's greatness, strength, and efficiency is determined and limited by the effectiveness or otherwise of each of the various component elements that contribute to the constitution of that nation. If an organization or an industry is not properly taking its part in the development of the national character you have just exactly the result as exemplified in the two advertisements read by the President, and you also have the result as instanced by Mr. Neilly in respect of the lack of consideration concerning the effect the increasing of freight rates is likely to have on an industry that contributes a very large proportion of the freight-carrying business of the railway companies. It seems to me, however, that in indicating the need for self-reliance it is not sufficient to be satisfied with the influence which an organization can exert in its own particular sphere; that influence should be extended so that it will have a beneficial effect upon the general national training. Also as regards the larger co-operative effort in national movement there undoubtedly is a great need for a more definite organization of a number of our industries; also there is a big work to be done in educating and preparing the rising generation efficiently to take their place in industry. That is a work which is common to mining, fishing, forestry, and agriculture, and which is not being done now in the way that it might. It is true facilities have been and are being created, but they are not being taken advantage of by any means fully; and it seems to me some effort might be made to inspire in the average boy and girl an ambition to take greater advantage of those facilities. That is a work in which all industrial and scientific organizations have or should have a common interest. Another common ground is the production of literature which will enable the youth of the country to inform themselves as regards the national resources and industries, and to guide and assist them in the selection of a career of usefulness. It is surprising how very poor the public libraries of the country are as regards the literature which is necessary to the full development of the industries in most communities. The libraries in many of our big industrial centres are very inadequately provided in respect of either reference

or educational works to enable the student to acquire or even to prepare him for the theoretical knowledge of, or to inform himself concerning, the details of the local industries, much less to afford him the means of acquainting himself concerning industries and opportunities in other parts of the country. Here again, in the provision of suitable literature, every industrial organization and every scientific organization can find a common ground for useful endeavour.

"THE WHITLEY SCHEME":

A Step toward Democratizing Industrial Relations

By C. V. Corless

(Annual Meeting, Montreal, 1918)

Discussions already presented to the Institute[1] on the problem of the relations of Capital and Labour have led to the conclusion that any final eradication of the existing antagonism must be based on an efficient socializing education of both parties to the dispute. To ensure that this is universal, such training must be given during school life. But an analysis of the present educational situation indicated that a radical reform in matter and methods of existing educational programmes is necessary, as a preparation for democratic social relationships, whether in industry or for what is more generally understood by the expression, 'good citizenship.'

In the progress of this discussion, the view has been variously expressed that this industrial conflict is a continuation, possibly the final phase, of the struggle, many centuries old, for democratic freedom, and that the solution of the difficulty will most readily be found by accepting this conception as a guiding principle and gradually conforming our views, our habits of thought, our mental attitudes to it. In politics, democratic peoples have attained to practical equality; in economics, they have not advanced beyond subordination. This "half slave, half free" condition of society cannot be permanent.

It will, of course, be at once clear to all who give earnest thought to the matter that any real improvement in this situation implies not so much a change of external formality in relationships between the parties to the industrial strife, as a

[1] "Widespread and Increased Intelligence, the Surest Remedy for Industrial Ills," *C.M.I. Bulletin*, September, 1916. "Our Educational System in Relation to Social Progress," *C.M.I. Bulletin*, December, 1916. "A Plea for Definite Training for Social Responsibility, by means of our Educational Institutions," *C.M.I. Bulletin*, April, 1917. "Educational Reform: Its Relation to a Solution of the Industrial Deadlock," *C.M.I. Bulletin*, December, 1917, January, 1918, February, 1918.

change of heart. No mere change in tactics will answer. Real co-operation, unity of aim and purpose, feeling of partnership in industry, can arise only from a clear-headed understanding of the deep, underlying, economic realities of the situation and a sympathetic determination to act on the square. When this economic understanding and this ethical determination are reasonably developed on each side, there will be no insuperable difficulty arising from creating machinery, organization, means, for getting together. But, if these mental conditions do not pre-exist, the most perfect machinery that can be devised for the purpose will be of no avail. There will be no intelligence to guide it and no motive power to actuate it. Hence, those who have this problem at heart and have any real understanding of the essence of it will make use of every available educational influence to this end. Clear understanding, essential cordiality, and downright good will may succeed even with imperfect machinery. But without these the whole arrangement becomes a sham, a makeshift, a temporary bulwark that only increases the disaster when it finally gives way.

Nevertheless, proper organization for getting together is not to be despised. Suitable and efficient arrangements for this purpose will go far towards maintaining a proper and sympathetic atmosphere and will assist in keeping up and in increasing good will. They will also furnish the best opportunity for continuing that democratic education whose groundwork we are pre-supposing as prepared during school life. Bungling organization, like badly designed machinery, causes much loss in friction and may lead to an early breakdown.

In this creation of democratic organization for unifying the aims of Capital and Labour, Great Britain is once more the pioneer. We instinctively turn to her for industrial experience, as a child turns to a wise parent. Her experience in industry is many centuries older than ours. Her labour is much more highly unionized. Her Trade Unions have passed through two centuries of struggle. Her differences between Labour and Capital are more clearly defined. Her class distinctions, for other (historical) reasons, are more marked—a fact that

has added to the bitterness between Capital and Labour. These conditions (together with others briefly outlined in previous contributions to the Institute) had brought the industrial dispute in Great Britain to such a stage that, by 1914, many felt that such general strikes were imminent, as would amount almost to, if they did not end in, a revolution. The war suddenly diverted attention from the quarrel. Though some domestic bickering has continued, all parties loyally joined hands in the superhuman effort against the common enemy. The war has, at least for the present, removed from Capital all self-complacency, which was a large factor in the domestic strife. The nation is already face to face with an inconceivable debt which is mounting at an appalling rate. The food supply is threatened. The nation is about to put forth its extreme exertion. There is no room now for old quarrels. Dust and cobwebs have been cleared away. England is never at her best until her back is to the wall. It required three years of war to brush away the last cobweb of self-complacency. She is now not only thoroughly aroused to fighting mood, but has had her creative energy quickened by the crisis. In the awful throes and agony of the past year of war, Britain brought forth an industrial idea which, if broadly and wisely backed up in future by educational preparation, seems calculated to effect such a revolution in industrial relationships as will remove the malign social results of the pernicious economic policy followed since the industrial revolution of a century ago. In the blackest year of the war, just past, the British Government appointed a Commission whose principal work was to inquire into the causes of industrial unrest and to make suggestions for removing the causes of discontent. The work was quickly and thoroughly done. The whole country was divided into eight industrial areas to each of which was detailed a small Commission of three, consisting of one representative of employers, one of labour, and an impartial chairman. Their reports will prove of great economic value. While these industrial commissions were at work, a short preliminary report was sent to each by a sub-committee of the recently created Reconstruction Department, which at that time had merely the

status of a committee appointed to consider the whole problem of industrial relations from the standpoint of post-war reconstruction.

The chairman of this sub-committee was Mr. Whitley, whose name, for brevity, has been attached to the committee, to the report, and to the general scheme embodied in the report. The broad recommendation of the Whitley Committee was the establishment in every organized trade of an Industrial Council, representing both employers and workpeople, and having as its object "the regular consideration of matters affecting the progress and well-being of the trade from the point of view of all engaged in it, so far as is consistent with the general interest of the community." The recommendation, modestly called an "Interim Report on Joint Standing Industrial Councils," was, in June of last year, sent to each of the eight small Industrial Commissions, who quickly secured for it a consideration by more than one hundred Employers' Associations and Trade Unions all over the country. The greatest interest in the proposal was manifested both by the industrial bodies concerned and by the press. There appeared to be at once a general feeling of relief that a possible solution had been found for what had come to be regarded as practically a deadlock. Nothing could indicate better than this feeling of relief the essential soundness at heart of both employers and employed. By October the replies had been received and correlated. The answers of nearly all of the Trade Unions and of most of the Employers' Associations were "overwhelmingly in favour of the adoption" of the general principle of the Whitley Report. Backed thus, the Minister of Labour on October 20th informed the Employers' Associations and the Trade Unions of the decision of the Government to adopt the Whitley Report. The document announcing this decision by the Government made it clear:

(1) that Joint Standing Industrial Councils should be established in all the well-organized industries with as little delay as possible;
(2) that these Councils would be considered by the Government as "official standing Consultative Committees on

all future questions affecting the industries which they represent" and would be the "normal channel through which the opinion and experience of an industry will be sought on all questions with which the industry is concerned"; and

(3) that the Councils are to be "independent bodies electing their own officers and free to determine their own functions and procedure with reference to the peculiar needs of each trade." These autonomous councils will thus "make possible a larger degree of self-government in industry than exists to-day."

These Joint Standing Industrial Councils, of national scope for each well-organized trade, will be supplemented by District Councils and these again by Shop Committees, on both of which masters and men will find equal representation.

The scheme has met with the approval of the Council of the Federation of British Industries, the most representative organization of employers in Great Britain, and of the Trade Union Congress, and to all appearances is in a fair way to success.

Mr. Wilson Harris is responsible for the statement that the idea of Joint Councils of masters and men originated with Mr. Malcolm Sparkes of London, an employer in the building and allied trades. He had "laid before the men's unions in these trades a memorandum on industrial co-operation. The Painters and Decorators took the memorandum and applied it." Their experience with the Industrial Councils already extends over about a year and has proven their practicability. The original purpose of these Joint Councils was, to use their official statement, "to promote the continuous progressive improvement of the industry, to realize its organic unity as a great national service, and to advance the well-being and status of all connected with it." This, as a spontaneous expression of idealism by a workmen's organization, is of deep significance. The District Councils in this trade have met regularly now for about a year under the masters' chairman and the men's chairman alternately, and have successfully carried out some important constructive work at various centres in the country,

besides averting some disputes. The Whitley Committee is said to have received the original suggestion from this memorandum by Mr. Sparkes and elaborated it. It may later prove to be true, as in many other great movements, that when the time is ripe the same idea springs up in many minds at about the same time. Perhaps I may be allowed to remark in passing that the psychology of the social mind must never be lost sight of, if the study of the psychology of the individual mind is to be most fruitful. As well to understand the anatomy and physiology of the hand without reference to the alimentary, circulatory, and nervous systems, as hope to succeed in a study of psychology of the individual mind without reference to the social mind with, and in, which it functions.

On considering the question of representation a little more closely, it seems probable that the labour representatives on the District and National Councils under the Whitley Scheme will all be trade union leaders, while the representatives of the employers will all be professional managers. The workman at the bench or lathe or loom or in the mine or elsewhere is generally not in close sympathy or close touch with either. If he is to feel a real co-operation between those who direct and those who perform the work, it will be through the Shop Committees. Success of the scheme will largely depend on perfectly frank, human intercourse between the representatives of both Councils and Committees, but above all, of the Shop Committees. If, as is hoped, "such an atmosphere will be created that trade disputes will never be carried to the breaking point," there will have to be, of necessity, the greatest sympathy, frankness, and cordiality between the representatives of the workmen and of the management on these Shop Committees.

Some difficulties will come to mind at once. In the first place, the scheme does not appear to provide for those industries in which either employers or workmen are unorganized. These can be encouraged, but cannot be forced, to organize. Again, in partly organized trades, the non-federated employer who insists on playing a lone hand, or the non-unionist workman, may refuse to be bound by the decisions of the Com-

mittees or the Councils. Probably steady pressure by those who are organized, added to continued success of the scheme, will force or tempt these to join. A further difficulty that suggests itself arises from the fact that the general public is not represented on the Councils. If the employers and workmen of any given trade work in perfect harmony, what is to prevent them from combining to increase the price of their product so as to raise both dividends and wages beyond a point that will be just to the general public? Possibly that might be corrected by combining this scheme in some way with the principle of the co-operative societies that have become so widespread and so highly developed in England. But experience will no doubt find a solution for these and other comparatively minor difficulties, if only the scheme for breaking the great deadlock justifies the high hopes that have led to its adoption. The great change that has come over men's minds with reference to organized industry is well shown by the following quotation from the Report of the Commissioners of the West Midlands Area. They say: "The best security for industrial peace is organization of both employers and employed. If the men are badly organized, the result is unauthorized local strikes; if the employers are not strongly federated, you have a minority which causes trouble. . . . We therefore recommend that employers' federations representing a substantial part of an industry should have disciplinary powers over recalcitrant members." Similar sentiments are expressed by several of the other Commissions. These statements are almost incredible in view of the general attitude of employers towards organized labour a few years ago. Truly the war has opened the eyes of the management class.

Political democracy was greatly advanced in Great Britain last year by the enfranchisement of 8,000,000 new voters. Industrial Democracy has now started on its course with the historical document promulgated by the Minister of Labour, which may be considered as its constitution. It undoubtedly has many rocks and shoals to discover, but that the right general course has been chosen there can scarcely be a doubt. This is by far the most interesting and far-reaching experiment in the

improvement of industrial relations ever attempted in any country. When the history of Great Britain during the twentieth century comes to be written, the year 1917 will stand out as the date on which the Magna Charta of Industrial Democracy was won—a date that may stand beside 1215 in importance. But one does not need to have a profound knowledge of history to recall that the Great Charter of Political Liberty, won seven centuries ago, was merely a starting point, a broad statement forecasting a freedom much of which had to be struggled for in the future and won bit by bit during a long period of time. "The Bill of Rights," "The Habeas Corpus Act," "The Act of Settlement," the great "Reform Bills," are a few outstanding milestones marking success in this long struggle. When the barons brought King John to his knees, long centuries had yet to elapse, a civil war had to be fought, a king executed, and many other struggles carried out, before the full rights of parliament were finally assured.

Such facts as these should warn us against mistaking the forms of liberty for the reality. They should warn us, too, that the growth of real freedom is slow. The creation of Parliament, the symbol of liberty, by no means meant that Parliamentary liberty had been finally won. So now. These Joint Industrial Councils and Committees, these new symbols of industrial freedom, are merely organizations created for the purpose of winning and defining democratic freedom in industry. The long training in the orderly method of securing political liberty through parliament will, no doubt, prove of great value here. But while the new Joint Industrial Councils and Committees express clearly a general recognition that workmen have rights not yet obtained, including a right to share in the responsibility of defining them, the actual formulation and winning of these rights are in the future.

It is, however, a great advance step that industrial civil war should end in the creation of the means for the orderly consideration, working out, and definition of those rights, by the deliberate use of discussion on equal terms in the open, in place of under a constant threat of the exercise of might. Democracy has herein scored another great win. It is a long

step forward in civilization when it is recognized for any new field that social progress (in this instance, in the industrial field) should be by a steady and orderly adaptation of social institutions and laws to changing conditions, under the action of free discussion and the pressure of public opinion thus created; and when it is further recognized that the primary condition of progress under such free discussion is such a flexibility and sensibility, combined with such an efficiency, of organization in our representative institutions, as will make the conclusions reached by these bodies a true generalized expression of the best opinion they are intended to reflect. How to combine this sensibility to the best real opinion with a stability that will ensure a steady ship making progress on a true course, a ship that does not rock with every temporary wave of opinion nor drift with every current and breeze of social theory that impinges on it, is a problem whose solution has been fairly successfully worked out by long experience in political democracy. Much careful thought and probably some disappointing experiments will be required before an equally successful combination of checks and balances is secured in Industrial Democracy.

But industrial democratic methods must surpass political methods in efficiency, which has always been their great weakness. Let us admit, once for all, that cumbersome machinery causing inefficiency cannot, and will not, be tolerated by either masters or men in democratic industry. If democracy in industry has to be won at the cost of efficiency in the highest sense, then it will prove not an assistance, but a hindrance, to social progress. For it must be recognized as an economic axiom that the greatest social advance can be obtained only on the basis of the most efficient production of those goods and services necessary for the satisfaction of human wants. Only a high degree of efficiency in economic service of all kinds, rendered by all in proportion to the ability of each, together with a fair and just distribution of the wealth thus produced, can secure a high standard of life for everyone, act as incentive to everyone to bring to bear his best efforts, and ensure at the same time that leisure for social welfare and self-improvement on which the progress of human society depends.

But I have no hesitation in expressing the opinion that the full application of the principle of democracy to industry will prove to be the most successful experiment in increasing efficiency in the truest sense yet tried. For I have more than a suspicion that efficiency experts, so self-styled, have had their attention so engrossed by the study of microscopic details that they have missed altogether their main principle, the very foundation on which any true theory of efficiency must be built. They have become so enamoured of the stopwatch and statistical method that they have ceased to look around them at the broad facts of human nature lying patent to all. Expert observation is always dangerous because it implies limited observation. The greatest resource in industry, till now remaining almost untapped, is the human will, the fountain-spring of all conscious human activity; and the greatest present industrial inefficiency and loss results from conflict of wills. If the full response of the human will can be secured for any enterprise or any purpose whatever, the entire ability of the individual is available. Without this, there may be reluctant, inefficient activity, drudgery; with this, there is the joy of creative work, a calling into play of the entire physical and mental resources of the individual, to an even greater extent than he himself is aware of. The former wearies, while accomplishing little; the latter rejuvenates, while producing much. Students of conservation and students of efficiency, which should be merely a department of conservation, have not given this fundamental principle the attention it deserves. In England, unskilled women, having the will to do their best for war purposes, have doubled, trebled, and frequently quadrupled the output of skilled men working under conditions of pre-war reluctance. Have you never seen equal results under a favourable contract system? If we could, by a single stroke, tap this resource to the full the day the war ceases, the incalculable war debts of all the belligerent nations would quickly melt away, there would be produced an abundance of all necessary goods and services for everyone, and there would be abundant leisure for enjoyment and improvement. It is this paralleling of human wills that is the core of the problem of the "Democratization of Industry."

This expression, "The Democratization of Industry," does not, as some may fear, imply a condition of semi-anarchy, weak organization and uncertain discipline. It is a form of organization suited for, and possible of effective use by, only the highest type of civilization; it is impossible for a poorly developed type—a fact remarkably illustrated at this moment by conditions in Russia. Democratic civilization is a living, growing type; one whose fundamental principle implies the assimilation, into the organized mind, of the best opinion of its members; a type that has the organization and adaptability to external conditions produced by vitality; a type whose aim is perfect development, not mere bigness and power; a type whose growth is from below upwards, whose guiding principle is, "of the people, by the people, for the people"; not a type proceeding "from the top downwards," hence artificial, rigid, inflexible, incapable of true growth or development to meet the highest human needs; the antithesis of the type superimposed by might, whose ruthless principle is the "blood and iron" trampling under foot of the rights of all when in conflict with an autocratic will. The democratic principle applied to industry means vastly increased, not lessened, efficiency. High industrial efficiency results from a number of conditions, among which are thorough organization and cheerful discipline. Every intelligent workman knows this as well as you do. Intelligent workmen, unless disaffected, feel pride in efficiency and dislike anarchy. The prime cause of the widespread disaffection that has existed is exactly those autocratic conditions which the democratizing of industrial relations will remove.

Industrial democracy merely demands that all the conditions of the co-operation of Labour and Capital in industry shall meet with the approval of both parties. Is there anything unreasonable in this demand ? With the two parties, each vitally and equally interested, is it unfair ? If the demands of Capital are just, surely it is only right and can do no injustice to anyone to discuss its claims in the open. If the fear of Capital is that Labour cannot understand the economic questions involved —a view that is probably true to a great extent at present— Capital has itself largely to blame, for it has had the greatest

say in framing the educational policy of the times. The "Whitley Scheme" will bring about a discussion on equal terms of all the conditions of co-operation of Capital and Labour. After many of the minor questions have been satisfactorily settled, inevitably, the question of the just distribution of the joint product of the wealth produced jointly by the co-operation will come into the discussion. Ever since the first parliament met many centuries ago, this has been in the lap of the future. It is now within measurable distance. It may happen tomorrow. It is for Capital to decide quickly what it is going to do about the question. Neither you nor I created the issue. But we are wanting in intelligence if we do not recognize what is inevitably ahead. What a world pity, if it turns out that Labour has not the breadth of view, or has any lack in the sense of responsibility, necessary for dealing with this vital question! What a world pity if, in the trying days ahead of us, Labour undertakes to deal with this question, without adequate knowledge of sound economics and social ethics, as a ballast! What a pity if, in place of such sound and sane insight into these vital matters, which ought to be as universal as general intelligence, Labour has been left to the misguidance of half-baked, utopian social theories picked up from a cheap sensational press or from irresponsible, but interested, agitators! And in political government in Great Britain, too, with the very large Labour vote, labour will be in a position to enforce its demands. And let us not forget that Great Britain is blazing a trail which Canada must soon follow. It is up to us to prepare for like conditions in future by training all our oncoming citizens to exercise intelligently these increasing powers, with their implied responsibilities. This we can most quickly and most efficiently do by a sound social training in all our educational institutions, whose courses of study and methods should be adapted without delay to meet the rapidly increasing social (including economic) exigencies of the times. Though the task is herculean and the need urgent, there is apparently no widespread, clear discernment of its urgency. No reconstruction scheme of greater importance or of more far-reaching consequences could be undertaken at the present moment. Clear

general enlightenment on economic and other social questions is the only safe course if our social evolution, under the influence of the profound social changes now in rapid progress in Great Britain, is to be orderly and progressive. Failure to acquaint ourselves with, and to adapt our institutions to meet, these conditions may spell disaster. Nor is it a question of whether we like it or not. Since I discussed this question with you a year ago, this mighty stride forward in Great Britain has been made. Even had we the desire to do so, we could no more stay this onward social movement than could Canute the incoming tide. But we can prepare for it, and it is our highest duty to do so, with no unnecessary loss of time.

It is not natural to me to be sensational or to be an alarmist. I am merely following a sense of public duty in stating these matters as they appear to me. But that this account is not a mere exaggeration of the quiet revolution that has taken place in England within the past few months, may be gathered from the following quotation from a speech by Lord Salisbury before his fellow-peers. Referring to the workmen, who had saved the country on the battlefields of Europe, and who have now at home, as he put it, "to work out their own salvation; they will," he said, "make many mistakes. Very likely they will adversely affect the property of many of your lordships. All these things are small matters. I earnestly hope that they will believe in us. I am quite sure that in the long run their good sense will prevail. But, whatever happens, we intend to trust them, my lords, and I believe that they will return the trust." What an eloquent surrender! The greatest victory of the British armies in Europe is the victory of Industrial Democracy, thus fully admitted.

Some of the ideals set before itself by Industrial Democracy may now briefly be summarized: If the capitalistic system is to remain, it must gradually be so reconstructed as to bring greater equality in status, in wealth, and in opportunity as between Capital and Labour. Further, it must never be forgotten that the State, the organized Public, is a partner in all business. The Government must gradually come to supervise all decisions

affecting the standard of living of manual workers who, in Great Britain, comprise 80% of the entire population. The system of unlimited wage competition has been proven a failure. It has reduced great numbers below any possibility of maintaining a decent standard of life. The best solution for this difficulty may not have been found. But social enlightenment, a strong desire to find such a solution as will be both just and efficient in its results, and the opportunity for unreserved discussion under the new Joint Councils and Committees, will find the true principle. In the meantime there can be no serious mistake in adopting, as quickly as practicable, at least temporarily, the principle of the 'Living Wage.'

We have in this new organization a frank recognition of the benefits derived from thorough and universal organization of labour on democratic principles. We have similar recognition of the benefit to be derived by the co-operation of employers. The acceptance of public service as the chief incentive for seeking high industrial efficiency may be yet in the distant future. The need of this higher incentive to replace the old incentive of private gain may be obscured by the many relatively minor matters immediately pressing. But the evolution of a still wider Joint Council—a National Council to represent every industry—an Industrial Parliament of national scope—with the purpose of co-ordinating all industrial endeavour so as efficiently to meet social and national needs, would seem to be the next logical step forward. Can we estimate the advantage to the nation such a complete national organization of industry would have proven to be, had it been in existence when the crisis came in 1914? This spirit of public service in place of the selfish desire for private gain as a guiding principle in business, as the true motive power of all industry, must be of gradual growth. Probably to a greater degree than one would suspect many already feel it as a ruling motive. It will require many a long year before the majority of men will act on the principle that their obligation to service is measured only by their ability—whether that ability consists in capital, intellect, or manual dexterity—to perform such service; before they will realize clearly that true ethics demands that every man be

a servant precisely in those matters of which he has the most intimate knowledge and in which he has attained the greatest proficiency. In a true democracy, we are all masters in respect to the interests of the community as a whole and servants in respect to our own special abilities. Our greatest mistake so far has been in considering industry as somehow outside of democracy. The great central aim of democracy is the highest welfare of the community as a whole. This can be attained only by opportunity for the greatest development of ability of the great mass of the population, not merely of a few. The resources of the nation must, therefore, be so organized as to meet in the best way the needs of all, not of a few or of any special classes. Nor can it be just that it should rest with a few to make, independently, great decisions as to policy in which the interests of all, or of many, are concerned. This principle must rule from top to bottom. How supremely important it becomes that for the exercise of the great responsibilities of citizenship in democracy—whether political or industrial—every individual should definitely be prepared! The Whitley Scheme is a remarkable step forward in democratizing industry, but, if its benefits are to be realized in reasonable time, it must be backed up by such general economic and ethical enlightenment as shall make clear to the mass of the population, and not merely to a few, the high ideals that inspire it and the most practicable means for attainment of them. This is the minimum technical preparation necessary for efficiently operating the most delicate, but powerful, democratic machinery yet constructed. Those who are deeply interested in industrial relationships (and we all should be), and particularly those who hold constructive views in regard to social welfare, who believe rather in setting in motion well-considered influences calculated to benefit society than in a policy of drift, or "wait-and-see," will, in their attempt to forecast our future social and industrial development and in their desire to set in motion such beneficial influences, find much to ponder over in the 'Whitley Scheme' and in its definite adoption by the British Ministry of Labour.

DISCUSSION

Prof. J. A. DALE (McGill University): I listened with admiration to the statement made by Mr. Corless of the parallel between the process of political democracy and industrial democracy. I don't think anyone who has watched closely the development of things, especially in England in the last year, can doubt that he has stated the case exactly as it is. I think the most wonderful point about it is the recognition in industrial fields that the only possible way in which the real responsibility, which is inevitably, though unconsciously, shared by the employer and the employed, can be exercised in conditions of great difficulty, is by actually and consciously sharing the responsibility. It is no use saying a certain class of people are not fit for responsibility. There is only one education for responsibility known to man, and that is the exercise of responsibility. If we want to do something we step in and do it, and there is no other way of finding out whether we are equal to responsibility or not. As soon as I heard that the planning was to be put into the hands of Mr. Whitley, a man of great capacity and energy, I felt sure that such a scheme would be produced as he has evolved.

It would be interesting to recall the remarkable parallel to the Whitley Scheme in the educational field. In the same way these educational problems have been before intelligent employers and employees for a long time. As a result of a long course of history it came about at the opening of the war that a group of men, partly employers, partly employed, partly university men, partly trade unionists, had come together in order to consider the educational problems of democracy—what part of the working out of the social fabric of the future was to be played by the school and the college. It is very significant that these problems arose after, and not before, the extension of the franchise. As Robert Lowe, of the first Compulsory Education Act, said, "Now we must proceed to educate our masters." That is the process which has been going on; and we have now reached a point at which the bulk of the organized working men in England are, within limits, educated men. They have reached that point which is always the most important in any development,

the point of self-consciousness. They have determined to step in and take a hand in their own education just as in politics they took a hand in their own legislation. So in the Whitley Scheme they have to decide what, in industrial relations, is the part they will take. The original position was, they were told what to do. The second position was, they were in the majority, and, having become conscious of the situation, they have prepared themselves for the responsibility to decide for themselves what they will do.

This educational scheme (presented to Parliament in a modified form by Mr. Fisher, the Minister of Education) was outlined in this way: In different parts of England various committees were formed, on which there sat men familiar with the industrial and educational conditions of the country. They sized up the educational need and the educational provision, found the weak spots in the system, and discussed how they were to be cured. Recommendations from them were made to a Central Committee, and drawn up in the form of a scheme, which was distributed to hundreds of trade unions and co-operative societies as well as to County Councils, local councils, university councils, and so forth. The body of criticism was sent back to headquarters. The final scheme that was drawn up will take its place in future by the side of the Whitley Scheme, and by the recent declaration of the British Labour party, as one of the most remarkable documents in the history of democracy. It will be only the beginning, and no doubt there will be many difficulties and disappointments, and some will lose heart; but that it is a milestone in the history of industrial democracy no one can doubt. Mr. Fisher, in the Bill which he has before Parliament at the present moment, has taken as many of those recommendations as he dare, bearing in mind the condition of the Treasury at the moment and the awful cost of war. But even so, it calls for an additional expenditure of ten millions of pounds sterling. He was told by many speakers he met not to be afraid of asking for that, huge as it might have seemed in pre-war times. We have got so used to war expenditure that we can look with equanimity at the prospect of adding another day's or two days' or another week's expenditure upon the war

basis for a reconstruction whose benefit shall be felt in happiness and prosperity for generations to come.

The weakest spot revealed in the enquiry I have referred to is one that is giving the greatest concern to all thinkers on the problems of industry and society; namely, the incomplete junction between school and after life. It is right to say, as Mr. Corless does, that the basis of industrial and social efficiency must be laid in school. The difficulty of translating this sound democratic principle into practice is very great, both educationally and administratively. However, in both ways the outlook is hopeful, because of the energy and thought and courage which are being devoted to experiments. No progress without experiment, is a pretty safe rule—and the educational field is full of experiments. The war has greatly stimulated originality and initiative in this as in other fields, but the movement had already been quickened by the industrial and commercial competition, and by the growth of the study of the science and practice of education.

The practical problems are of two kinds. One is the difficulty of knowing just exactly what is the right expression to give to the ideals which you want to teach. When you are handling classes of children it is no good talking in terms of generalities or you will get misunderstood. It is one of the next educational reforms to be carried out—to get the ideals we desire our children to live up to in their after life expressed in terms that are concrete and practical. The most important part of this reform, which is well under way, is to provide greater scope for initiative, originality, self-expression, and self-development in school. It is beyond question that here lies the most promising line of progress—leading to the production not of uniform mediocrity or even uniform excellence, but to the presentation and development of the pioneering spirit which has gained for our race all its achievements. In the same way, the spirit of social responsibility desired by Mr. Corless will best be fostered when the school is a real community in which the child bears real responsibility. Both these ask from the school practicable knowledge, and a will at the same time strengthened for individual initiative and disciplined to social co-operation.

The other problem is that of the passage from school to occupation and livelihood. Every observer has seen that too often there is a gap here, and many very interesting experiments have been made to guard against the loss, both to the individual and the State, of an interval of inefficiency. In too many cases it is not too much to say that inefficiency and unemployment are definite products of the educational system. I can only make the briefest reference to the development of continuation schools (which Mr. Fisher proposes to make compulsory up to the age of 18); but it is clear that the next great extension of education will be in the direction of the interlocking of the last years of school and the first years of livelihood.

With regard to another difficulty, I want to make a personal appeal. It is constantly said, and with truth, that an immense responsibility rests on our schools; but there is little realization of what that responsibility amounts to. We have not fulfilled our responsibility in the matter when we have appointed a teacher at a village school, perhaps at thirty dollars a month and no training. It is all very well to say the responsibility is on the school — it is not on the school until we have put in schools people we have trained to teach what we have decided that the children need. I once heard a distinguished minister say of a particular training class that the future of Canada is in the hands of the country school teachers. Of course, this is very largely true; but I could not help saying to him: "Do you know that those teachers are going out at an average salary of $25 a month ? Do you consider that a fair reward for carrying what you call the responsibility of the future of Canada ?" There is something wrong somewhere. I want to appeal for a wider and directer sharing of the responsibility of education. I know one industrial community near Montreal which has pitifully poor schools, attended by the children of employees of industrial companies whose shareholders live away, and pay a wretchedly small contribution to the school; the local board came to us at Quebec to beg a small grant to eke out existence. It is no use trying to teach social responsibility when those who have the power and ought to be exercising that responsibility fail to do so. Turn to the effort put forward at Shawinigan

Falls, where it is obvious that there is a social responsibility, because it is exercised in the sight of all. All you who have the chance of improving the school system in your own district should take every chance you can make. Our children will get the best out of education when we put our best into it. They will learn social responsibility best in a community where it is exercised and honoured. This is another true case of the superiority of the example over the precept, which is the profoundest educational principle. I emphasize this kind of preliminary difficulty in the teaching of citizenship in our schools because it is one you can help to remove. But my ordinary rôle is not that of discouragement, and I want to conclude with a note of hearty sympathy and congratulation on the view of industrial and educational democracy as outlined by Mr. Corless.

Mr. G. J. MACKAY: The Whitley Scheme, from the operation of which so much is expected in Britain, is, in Mr. Corless's opinion, a proper organization for the getting together of capital and labour. He is, however, convinced that neither it nor the most perfect machinery that can be devised for the purpose will be a success unless there is on both sides an adequate knowledge of sound economic and social ethics that will make possible a discussion, on equal terms, of all the conditions necessary to the co-operation of capital and labour. He is also convinced that this social enlightenment is possible only through the educational system of the country and that we in Canada should, no less than the people of Britain, undertake this great educational problem without delay.

My object is, not to discuss the question whether a foundation for such social enlightenment can be laid in our elementary schools, but to suggest to the Institute two lines of action open to them that will assist very materially in bringing about the desired results where they are most needed, that is, amongst our industrial workers.

Throughout Canada a beginning has been made in organizing systems of vocational schools. In Ontario a few of these schools have been opened and are doing good work. Their object

is to give boys between the ages of thirteen and seventeen years, who are destined for the industries, an education that will best fit them for their life's work. Here we have grouped together the boys who will later be the skilled workmen of the country, the class who are in most need of this industrial enlightenment. and at an age when their minds are still most receptive and yet sufficiently developed to grasp the problems of practical economics and social ethics. In those of our Ontario vocational schools that are fully organized these subjects have already a place on the curriculum.

The great stumbling-block in the way of fully developing this vocational school system is the initial expenditure necessary for providing buildings and equipping them with workshops. The smaller industrial centres find this almost prohibitive. The only feasible plan to surmount the difficulty is the appropriation of federal grants to the provinces for the assistance of vocational education. But for the war, the provinces would no doubt already be receiving this federal aid. The United States has preceded us here. Just a year ago Congress passed an Act providing very liberal grants to the different States to aid in vocational education.

If the Institute believes in the urgent necessity for the social enlightenment of our industrial workers, here is a field already open for the good work. The Institute can give most valuable assistance to two worthy objects by throwing the weight of its influence into the effort that is being made to secure a federal grant for the aid of vocational and technical secondary education in the provinces.

There is another fertile field that it is to be hoped will soon be open in England for the inculcating of this economic and social enlightenment, which the author of the paper under discussion so aptly says should be as universal as general intelligence. A bill is before the British Parliament to establish in England, immediately on the close of the war, a system of compulsory continuation schools. Under this system, all young people between the ages of fourteen and eighteen, who are not

attending full-time schools, will be compelled to attend continuation schools eight hours each week, these hours to be taken out of the working days. It has been found by experience that to make any progress in the education of this class of young people, their attendance at the schools must be made compulsory. The schools will probably be of the vocational type, part of the pupils' time being taken up with shop-work and part with continuing their general education. This system, besides improving the education of the young people, will insure their retaining what they received before the age of fourteen till they have reached an age where they will appreciate its value. Again, the United States is ahead of us here. Such systems are in operation in a number of States. This step in public education is receiving serious consideration from many thoughtful men in our country.

Can we conceive of any kind of school in which there is a better opportunity for instilling into the minds of all the coming workmen of the country a practical appreciation of economics, politics, and social and industrial ethics? Here we have all the boys we are most anxious to reach, at the right age, and just beginning their life in the industrial and economic organization of the country.

In my opinion, this question of compulsory continuation schools is worthy of consideration by the members of the Institute.

Mr. ARTHUR A. COLE: During the past year Mr. Corless has contributed to this Institute a series of papers of a very instructive and constructive character on this most important theme of educational reform. He has convinced us that the reform he advocates is essential to successful solution of the industrial problem, and in order that we may express our sympathy and agreement with his views, and at the same time take some action that will be helpful to the movement, I beg to submit the following resolution:

WHEREAS in view of the enormous importance that capital and labour should co-operate amicably, and in view of the fact that, in the opinion of this meeting, the present antagonistic relations between capital and labour are largely the result of economic misunderstanding of the true relationship of industry to the welfare of society as a whole; BE IT RESOLVED that this Institute endorses the general position set forth in the series of papers presented by Mr. C. V. Corless as to the necessity of educational reform as a basis for the correction of this misunderstanding; AND BE IT FURTHER RESOLVED that the Secretary of the Institute be instructed to forward a copy of this resolution, with copies of the papers in question, to the Engineering Institute of Canada, the Society of Chemical Industry, the Canadian Manufacturers' Association, the Pulp and Paper Association, the Textile Association, and other industrial national bodies, with the request that they consider the reform advocated, so that joint action can be taken in bringing the matter to the attention of the educational authorities of the Dominion.

The motion was seconded by Dr. J. G. DAVIDSON, who said: I agree with Mr. Corless that the educational preparation, through which all our prospective citizens go, fails to train them to solve the problems of society, and thus loses the greatest chance of working out any intelligent and fundamental solutions. The ordinary school education depends too much on the reproduction of words of textbook and teacher, and measures success by the accuracy of this imitation. Thus our children are not interested in the ideas behind the words, and are therefore at a loss when it comes to applying them in after life. The child who has learned in school to be interested in the things that come before him, and has been trained to interpret them in terms of ideas, will automatically carry that attitude into his life-work. And the workman who is interested in his work is never a mere labourer, but in his sphere a useful and competent member of society.

Mr. T. W. GIBSON: I must add a word to express my own appreciation, and that of everyone here, of these splendid papers. They set forth the results of the fermentation that has been going on for years, quickened as it has been by the gigantic events of recent years in industrial and commercial circles in the old land. And we in Canada cannot remain outside of this world-revolution that is taking place. The bringing together of capital and labour on a common platform, and the finding of amicable methods for the settlement of industrial questions has long been a dream which seemed to practical men incapable of realization. But there are few things outside of the possi-

bilities of human effort and human energy and human will when all these powers and faculties are engaged in the solution of a question. I believe the education going on has been sufficiently deep and extensive to force, and to enable individuals to adopt, the social rather than the individualistic ideal as the problem. It has remained for our generation to see these wonderful things about to be realized—in the words of Burns: "Then let it come, as come it may, and come it will for a' that, when man to man the world o'er, shall brothers be and a' that." The statement of the possibilities of settling industrial disputes in this friendly and amicable method is a step in advance so great and extensive as almost to be beyond our imagination to grasp the results that will flow from it. If it will mean the bridging of the gulf between the employer and employee, if it will mean their co-operation in the advancement of social and individual welfare, then I say we cannot extend to it too hearty a welcome or give to it too hearty a support. In respect to education we are all fully aware that our educational system does not yield the results we have a right to expect. Our boys and girls come from the public school with little or no sense of social responsibility. Their education in the big things of life begins only when they leave school. Instead of applying the knowledge and ideas which they are supposed to obtain in a public school they are thrown out into the world almost more helpless than if they had not passed through the system of education provided for them. There is a field for educational reform, as there is a field for industrial and political reform. In conclusion, may I be permitted to suggest that, as we have recognized, the mining industry has not so far had a representative in the halls of Parliament capable of expressing its wants and wishes and views, we could not select anyone better qualified to represent us in the councils of the nation than Mr. Corless.

Dr. GOODWIN: It means a great deal to the Canadian Mining Institute to have been the medium through which these papers will reach the public. Preliminary to the attainment of the high ideals which have been set before us, much must be done in the way of educating public opinion. In this connection

reference has not been made to one important and most favourable factor in the situation, namely, that Canada now has 300,000 men passing through a process of education which is largely purging them of excessive individualism and breeding in them the idea of co-operation, of intelligent co-operation. When those 300,000 men return we shall have a body of public opinion behind the ideals put forward in these papers—such a body as will give a great impetus towards the goal which we all wish to reach. As regards Federal aid to education, when we consider that Great Britain is prepared cheerfully to vote ten million pounds a year for this purpose, can we hesitate one moment to ask our Dominion Parliament to vote four or five million dollars a year to assist in the prosecution of this all-important work ?

The resolution as proposed by Mr. Cole was carried unanimously.

'NICU' STEEL AND ITS MANUFACTURE

By G. M. Colvocoresses, Humboldt, Arizona

(Annual Meeting, March, 1918)

In 1916 the world's production of nickel was 50,000 tons. Of this 85% was derived from ores mined in the Sudbury district of Ontario, such ores being essentially a combination of nickel, copper, iron and sulphur, containing on the average 65 pounds of nickel, 34 pounds of copper and 800 pounds of iron per ton; 75% of all the nickel recovered was used in the form of nickel-steel with an average composition of 3.0% nickel, 96.0% iron. In this manner approximately 37,500 tons of pure nickel found employment. The iron contents of the nickel ores mined in the Sudbury district during 1916 amounted to 650,000 tons, all of which was slagged off and thrown away during the process of smelting and refining. During the same year in the production of a finished product of nickel-steel some 800,000 tons of iron had to be drawn from other sources. The market value of the iron contents of the nickel ores mined in 1916 would be approximately $14,000,000 at the average prices for that year, or twice that amount at the 1917 quotations.

Such metallurgical practice is not conservation; it is not economic or ideal metallurgy; and the author will endeavour to prove that it will not be the practice of the future. In 1888, when mining and smelting operations were started at Sudbury, the ores were mined for their copper values, because it happened that in the particular mines which were first opened the percentage of copper was considerably higher than the percentage of nickel, and the value of the nickel was considered very problematical. These ores were accordingly treated by a process which was based on the metallurgy of copper and which, with some slight modifications, has been in use ever since.

The ore that was mined in 1916 contained on the average: 3.25% nickel; 1.70% copper; 40.0% iron; 25.0% sulphur; 20.0% silica; and 10.0% alumina, lime, and magnesia. This ore was first roasted, mainly in open heaps, where the iron,

nickel and copper sulphides were partially converted into oxides and the sulphur reduced to an average of about 10%. The roasted ore, together with some green ore and flux, was then smelted to a matte in blast or reverberatory furnaces. This matte, on the average, contained: 25.0% combined nickel and copper; 45.0% iron, and 25.0% sulphur. It was bessemerized like copper matte until the composition was approximately 80.0% combined nickel and copper, 1.0% iron, and 19.0% sulphur. The high-grade matte was then exported for subsequent refining and separation of the nickel and copper by either the Orford or the Mond processes. Both of these processes, which are complicated and expensive, result in a separation of the nickel and copper and the production of nickel or nickel oxide and copper or copper sulphate as may be desired. Three-quarters of the nickel product was subsequently combined with iron, mostly in open hearth furnaces, and eventually converted into nickel-steel; while the copper was used for various purposes for which this metal is suitable.

The British America Nickel Corporation, which will shortly start smelting operations, intends to follow the same methods until bessemer matte is obtained, and will then separate the nickel from the copper by roasting, leaching and electrolysis.

By all the present methods, the operators aim to save in one form or another as much of the nickel and copper as possible, but they absolutely and deliberately throw away all of the iron and all of the sulphur as well as the insoluble content of the ore. The mechanical and metallurgical losses, moreover, amount to about 20% of the nickel and 17% of the copper in the original ore.

Assuming that this year the value of iron is $30 per ton, the value of nickel 40 cents per pound, copper 25 cents per pound, and sulphur (in medium grades of sulphuric acid) two cents per pound, then, in round figures, the 1,600,000 tons of ore which should be mined in the Sudbury district in 1918 will have a gross value in nickel of $41,500,000, of which $33,000,000 will be saved and $8,500,000 will be lost. The copper will.

have a gross value of $13,500,000, of which $11,000,000 will be saved and $2,500,000 will be lost. The iron will have a gross value of $19,000,000, which will all be lost, and the sulphur will have a gross value of $16,000,000 which will be lost. So the gross value of the useful metals in the Sudbury ore production for this year will amount to a total of $90,000,000, of which $44,000,000 will be saved and $46,000,000, or 51%, will be lost. In passing it may be mentioned that the value of the precious metals in this ore will be about $800,000, of which approximately 33% is recovered by present methods. The figures given above are all gross; the net value of any metal or product is, of course, the difference between the actual sale price and the cost of production. If by new methods the cost of recovering the iron, sulphur, nickel, and copper now lost equals the actual market value of the products so saved, obviously the advantage from a commercial standpoint is nil; but the author contends that a large part of these lost metals can be recovered at a cost which will admit of a satisfactory profit, and, if this contention is demonstrable, the question may pertinently be asked whether or not Canada can afford to waste annually such a quantity of her resources, valuable at all times, but now doubly so in time of war, when every nerve must be strained to out-general the enemy, not only on the field of battle, but also in the field of industrial efficiency.

When, about the year 1890, the first matte from Sudbury was sent to the Orford Copper Works, it was treated by a process that provided for the recovery of the iron as well as the nickel and copper, but for certain reasons this process was not satisfactory; and with the development of the present Orford or 'salt-cake' process for separating the nickel and copper, the old method was discarded, and thereafter the iron in the matte was slagged off and lost. So the Sudbury ores have nearly always been treated like copper ores up to a certain point, being roasted, matted and bessemerized like copper ores, though the later stages are different, since it is necessary to separate the nickel from the copper by methods of treatment which have been developed and perfected over a period of 30 years and which have proved successful and profitable. Nevertheless, the author

claims that the entire present system of treating the Sudbury ore is wrong. Since this ore is essentially an ore of iron rather than an ore of nickel and copper, it should be treated as an iron ore; particularly since the nickel in large proportion must eventually return to a combination with iron, in which form it will actually be used, and because we now believe that the copper may also be used to some extent in combination with the iron quite as advantageously as the nickel.

In 1901 and 1902, the metallurgists of the Lake Superior Corporation (operating at the 'Soo') undertook to apply a radically different method of treatment of the Sudbury ore. They found that some of the ore contained a high percentage of nickel but very little copper, and by utilizing ore of this character (6% nickel and 1% copper) and partly separating such copper, they sought to produce directly a ferro-nickel. Their work was not a commercial success, principally because they could not satisfactorily separate the copper from the nickel, but the · had at least an idea which was worth something, and to Mr. Sjostedt and Mr. Ulke great credit is due for having started out to make a real improvement in the metallurgy of the Sudbury ores. At that time the author was employed by the Canadian branch of the Orford Copper Co., which was re-treating the blast furnace matte produced by the Canadian Copper Co., and raising it to a 72% (combined nickel and copper) matte for subsequent shipment to the Orford Works in New Jersey, and he was deeply interested in the process from a theoretical standpoint and thought that some method which could recover and utilize the iron in the Sudbury ore would eventually be developed and generally adopted.

The author had later an opportunity to learn something of the metallurgy of the garnierite ore in New Caledonia, which was being mined and exported to France, England, and the United States. Garnierite[1] is essentially a hydrous silicate of nickel and magnesia in a gangue of serpentine rock, and the average composition of the ore as mined may be given as follows:

[1] Richesses Minérales de la Nouvelle Caledonie, by M. E. Glasser; published by Vve Ch. Dumod, 49 Ince des Grands Augustines, Paris, 1904.

Water (uncombined)	20%
Water (combined)	10%
Nickel	5%
Iron	10%
Silica	33%
Magnesia	15%

The nickel and iron both occur as oxides, and there is also from 1% to 3% of lime and manganese, and less than 1% of cobalt and chrome. Like the Sudbury ore, the New Caledonia ore has nearly always been treated like an ore of copper. It contains no sulphur, but sulphurous material (generally gypsum or iron pyrites) is smelted with it to form a matte which is roasted, reduced, and refined repeatedly until impure nickel results. In 1880 a different process[2] was tried in New Caledonia: the ore was smelted in a cupola or blast furnace to a 'fonte' or ferro-nickel, which was in fact an impure nickel pig containing 66% nickel and 24% iron: but this process did not succeed, partly because of the small scale on which it was operated, of the lack of skill on the part of the operators, of the general difficulties attending smelting in New Caledonia, and of the expense of removing the small percentage of sulphur which was transferred to the 'fonte' from the impure coke used in the blast furnace. The New Caledonia nickel ore contains only 10% of iron, but there exist on that island great deposits of hematite which contain 40% or 50% of iron with up to 0.5% of nickel, and which can be mined very cheaply; there are also enormous deposits of coral limestone available for flux, and to-day, when we know more about smelting iron than they did in 1880, it seems logical that the New Caledonia nickel ore should be smelted with the iron ore and reduced directly to alloy-pig, and subsequently refined to alloy-steel without passing through the matting stage and the long series of subsequent treatments.

Except for a short run with an electric furnace in 1907, the New Caledonia ore has never been treated in this manner since the failure of the old operations; but it may be interesting to

[2] Private communication from Thomas Moore, formerly Government Chemist at Noumea, N. Cal.

note that in another part of the world a considerable amount of the New Caledonia ore has recently been smelted with iron ores from other sources and the nickel-steel produced is said to be of the highest quality and in every respect satisfactory, and as soon as the present war is over and freight conditions return to normal, it is probable that large quantities of New Caledonia ore will again be shipped for treatment in this manner.

It is my opinion that if New Caledonia is to continue in competition with Canada as a producer of nickel, the present method of treating the New Caledonia ores will have to be superseded largely by this manufacture of nickel-steel by direct smelting of the nickel ore with iron ore; but in this competition Canada will still have a great advantage, since the percentage of iron in the Canadian nickel ore is four times the percentage in the nickel ores of New Caledonia. True there is no sulphur in the New Caledonia ore, but I believe that sulphur in the Canadian ore can be roasted out with actual profit rather than with loss. The absence of copper from the New Caledonia ore may be considered an advantage, but the author hopes to prove that the copper in the Canadian ore is just as valuable as so much nickel, although elsewhere copper is only worth half as much per pound. All other conditions, moreover, strongly favour Canada as against its distant but by no means negligible competitor.

In 1905 experiments were made by the late Major R. G. Leckie and my good friend and associate Harry A. Morin on the smelting of the Sudbury slag for the production of iron, and in some respects their work was the forerunner of our present process for the treatment of slags. Shortly after, experiments on smelting the nickel ores in an electric furnace were again undertaken at the "Soo" under the direction of Dr. Haanel and Mr. Sjostedt,[3] and some cupro-nickel pig iron was produced; but if I am rightly informed, they did not follow up this work because of the difficulty of separating the copper minerals from the nickel minerals and their belief that it was necessary to make such separation before a valuable alloy-steel

[3] Report to Canadian Government on Electric Smelting, by Eugene Haanel, Ph.D., Ottawa, 1907.

could be produced. About this time the author was connected with a company which owned some deposits of impure iron in another section of Canada, and in studying possible methods for the treatment of these ores he first made practical acquaintance with the electric furnace, and realized the possibilities that electro-metallurgy was opening up for the iron and steel industry and for the treatment of impure and complex material. In 1908 the author visited Mayari, in the eastern section of Cuba, where a limonite ore containing a little nickel and chrome was being mined and treated by roasting and sintering and, after shipment to the United States, by smelting to a pig which was eventually refined (with the removal of the greater part of the chromium) to produce the 'Mayari Steel' now well known in commerce. This steel is really a ternary alloy, a nickel-chrome-steel, the percentage of nickel being about 1.40, the chrome being kept below 0.5%.

Since 1901 the author kept in mind the possibilities of treating the Sudbury ore as an iron ore rather than as a copper ore, and of smelting it to a pig rather than to matte. The development of the multiple hearth roasting furnace provided a means of desulphurizing the ore as far as might be desired and at a comparatively small expense, and the development of the electric furnace provided a means of further reducing the sulphur in the calcined ore during smelting and refining to a point far below that required by the specifications for high-grade steels. The copper, however, still remained a stumbling block and to all intents and purposes rendered it impossible to determine how the ore could successfully be treated in this manner, because no process so far discovered could make a satisfactory commercial separation of the copper sulphides from the nickel and iron sulphides in the ore; yet if one admitted that the presence of copper was harmful to steel and particularly to high-grade steel, it was absolutely necessary that some means should be devised for making this separation before proceeding with the smelting and refining.

Developments in iron industries were, however, progressing rapidly, and metallurgists were more and more frequently inquir-

ing as to the real effect of copper in steel and the basis of the prejudice which existed on this subject. In 1909 Prof. Burgess with Mr. Ashton[4] experimented at the University of Wisconsin on alloys of iron, nickel, and copper and came to the conclusion that when pure iron, nickel and copper were mixed in certain proportions, and if care was taken to avoid too high a proportion of carbon, the copper was not detrimental to the resultant product, but appeared to replace a certain amount of nickel and to affect the steel in a similar manner. Mr. Clamer, of Philadelphia, was also experimenting along the same lines, and obtaining similar results, his work being practical as well as theoretical; and his conclusions were summarized in an excellent paper entitled "Cupro-Nickel Steel," which was presented to the American Society of Testing Materials in 1910. Mr. Clamer[5] took out several patents for the cupro-nickel steel which he manufactured, and for a process for the manufacture of such steel. These comprised the treatment of matte by roasting and smelting with iron ores for the production of alloy-pig which was subsequently refined to steel. This process was a long step in advance, since Clamer kept the nickel and copper in combination and also kept a part of the iron, which had occurred in the ore in combination with the nickel and copper, in his finished product; but he still followed the original system of partly desulphurizing the ore and matting, and in so doing a large part of the original iron was slagged off and lost.

Meanwhile, the International Nickel Co. had developed 'Monel metal',[6] a natural alloy of nickel and copper, containing about 70% of the former and 27% of the latter, with a little iron and other impurities; and although this metal was developed mainly to provide a substitute for bronze and in some measure as a cheaper substitute for nickel, some clever people in the United States seized upon the opportunity to purchase Monel metal scrap as fast as they could, and to make with this Monel metal an alloy-steel, which they passed off as nickel-steel, and which

[4] Electro-Chemical and Metallurgical Industry.
[5] U.S. Patents Nos. 1050342, 1016549, 1086314; Canadian Patent No. 134544.
[6] Canadian Patent No. 96764.

in practice was found to be about as good as nickel-steel. Actually, this Monel-metal-steel, which was in effect a nickel-copper steel, passed all the tests of the United States Government, and entered into the manufacture of a large number of armour-piercing shells, and was also utilized to a considerable extent for automobiles and in other industrial lines of manufacture requiring a high-grade alloy-steel. The author believes that the Monel-metal-steel met the requirements of the manufacturers and users as well as the nickel-steel which it replaced at a considerably lower cost.

These developments had changed the whole outlook as far as the manufacture of alloy-steel was concerned, for they had practically proved that nickel and copper might be combined to form an alloy-steel without any disastrous effects resulting from the presence of the copper, and if Monel metal, representing the combined nickel and copper in the Sudbury ores, might be mixed with outside iron to form an excellent alloy-steel, why would it not be possible to retain with the nickel and copper the iron originally combined with them by nature and to manufacture therefrom a steel that would be equally good ? In fact, the Sudbury ore became no longer valuable only for its nickel-copper content, but also for its iron, and it was a very valuable alloy-iron ore containing three metals, which might be kept in combination throughout the entire process and eventually turned into a valuable alloy-steel.

The author's old ideas, notes, and experiments in Canada, New Caledonia, Cuba, and elsewhere were therefore reconsidered, seeking a practical method of treating the Sudbury ore. The result was a process for the direct manufacture of nickel-copper alloy-steel from the Sudbury ores and from the blast furnace slags which had been made in that district, and for the production of an alloy-steel which we now call by the trade name of 'Nicu Steel' and which has been manufactured in laboratories and on a small scale at intervals during the past five years, and under commercial conditions for the first time in East Montreal during the fall of 1917.

Our process in principle is very simple. The treatment of

the ore is based upon the assumption that the Sudbury ores are primarily iron ores rather than nickel-copper ores and that the ternary alloy which has been formed by nature in these ores is a valuable one for conversion into actual commercial use, providing the proportions of the three metals combined therein are properly regulated and the combination made complete and homogeneous. The 'Nicu' steel produced is, therefore, in reality a modified natural alloy, and we remove the main objection to natural alloys (which is the varying composition of the product) by so mixing the ores as to assure a practically uniform composition, and by adding during the process additional iron-bearing material which will reduce in proportion the content of nickel and copper if this be higher than desired, or by mixing the ores with Sudbury slag in order to ensure the same result.

The ore, as taken from the ground, contains 25% sulphur, which must be removed before it can be treated in a blast furnace or electric furnace; hence the first step in the process consists in crushing the ore to the necessary fineness (which we now find need not be less than ½ inch) and in roasting it completely so that the resultant calcines shall not contain more than 0.50% sulphur; in practice we have been able easily to reduce this sulphur to 0.30%. The roasting, of course, requires some fuel, but not a great deal, since the ore, once ignited in a proper furnace, will roast itself down to 3% or 4% sulphur, and only requires fuel to drive off the balance of the sulphur. We believe that at some future time, when we are able to provide satisfactory equipment for carrying out this process on a large scale, the roasting will be carried on in multiple hearth roasters, and with such equipment the sulphur can be recovered at a profit and manufactured into sulphuric acid or possibly into elemental sulphur by the Hall[7] or Thiogen[8] process or some other process which may be developed later. I do not intend at present to dwell too much upon the value of the sulphur contained

[7] Mining and Metallurgical Society of America, Bulletin No. 76, Sept. 30, 1914, page 134.

[8] *Mining and Scientific Press*, Vol. 103, 1911, page 386. U.S. Bureau of Mines pamphlet, "The Wet Thiogen Process."

in the ore, because I do not yet know that it can be utilized with commercial profit, considering all the conditions of the industry. This is a subject which holds out great promise for the future, and which should be carefully studied, but it seems possible that a large percentage of the sulphur in the ore can be recovered in a useful form with profit to the operating company and with advantage to the Canadian industries which are employing sulphur, for which there is at the present time a considerable demand. In 1915, 46,000 tons of sulphur was imported into Canada, and the imports at present must be far larger, yet 400,000 tons of sulphur are sent up annually in smoke from the Sudbury ores.

In the roasting furnace we shall probably plan to raise the temperature of the calcines in the lower hearth of the furnace to such a point that, when mixed with a proper binder, they will nodulize and be suitable for treatment in a blast furnace; thus rendering it unnecessary to employ electric furnaces for their reduction. Nodulizing certain ores of iron in roasting furnaces or special kilns is an established practice, and there is no reason why it cannot be accomplished equally successfully in the treatment of the Sudbury ores.

After the ore is roasted we have practically an iron oxide ore which is hematite or in part magnetite and contains oxides of nickel and copper. The next step is the reduction of this ore, which may be carried out in an iron blast furnace using coke, or in an electric furnace using coke, coal, or charcoal for a reducing reagent. In any case, limestone must be added as a flux to slag off the silicates, as is usual in smelting iron ores. So far our actual operations have been carried on in electric furnaces only, since for obvious reasons it is not easy to start a process of this kind on the very large scale which the operation of a blast furnace involves, so that the data which I am now able to give are based upon the electric furnace practice. They seem sufficient, however, to point the way also to successful blast furnace operation. A theoretical comparison of the blast furnace with the electric furnace for the reduction of this ore has been made under many varying conditions, and although with

very cheap electric power it may appear that the electric furnace would have some advantage over the coke-fired blast furnace, still in practice it does not seem to work out this way, and for operating on a large scale the author is convinced that blast furnace treatment is preferable to treatment in the best type of electric furnace, although possibly in the future conditions may change so as to give the electric furnace the advantage.

The product of the reducing furnace is an alloy pig containing iron, nickel, and copper in the same relative proportions as in the ore orginally charged into the furnaces, or in such altered proportions as may have been brought about by the addition of other iron-bearing material, and we are able to regulate the carbon as may be desired. Operating on a large scale we would plan to run the molten pig directly into a refining furnace, either an open hearth or electric furnace, or possibly some modified type of bessemer converter, and to turn the pig metal into steel, using a little lime to slag off the remaining sulphur, and reducing the carbon with hematite in the usual manner. In this portion of the process great care is required in order to make exactly the alloy-steel desired and to regulate the quantity of the nickel and copper which must enter into the finished steel.

Up to the present, not being equipped for continuous operation of the process, we have been obliged to allow the pig metal to cool and then to recharge it into the refining furnace. At first an electric furnace was used for the steel making and good results were obtained except that the heats were comparatively small and required more time and expense than was desirable. Later, the pig metal was charged into an open hearth steel furnace of the ordinary type and was converted into open hearth alloy-steel with perfect success. The treatment of this nickel-copper pig iron in the open hearth furnace is entirely sarisfactory, and in every way comparable to the treatment of ordinary pig iron, and it required no more time or expense to make the alloy-steel than is required for the production of ordinary carbon steel by the same method. The data we have gathered seem to show that if the preliminary roasting is carried sufficiently far, the blast furnace pig will not contain

more than 0.5% sulphur, and this is well within the limits permissible for treatment in open hearth steel furnaces.

We are operating, of course, on a combination of three metals, instead of on a material containing only one metal, and we are treating these three metals as if they were one and carrying them in intimate combination from the start to the finish of the process. In doing this there are certain special considerations which have to be taken into account, and we have already learned some valuable practical points in connection with our operations, and will, no doubt, be able to improve the practice as we gain more experience.

The process which I have described above is also applicable, with a few modifications, to the blast furnace and reverberatory slags, of which there are some 8,000,000 tons now available in the Sudbury district, containing on the average, about 40.0% iron, 0.40% nickel, and 0.20% copper. This is an artificial iron ore with so little sulphur that it does not need to be roasted; it carries, however, a much lower percentage of nickel and copper than the natural ore and rather more copper than we desire in proportion to the nickel, and it is purely a question of commercial profit as to whether or not these slags can be utilized to advantage for the production of over 3,000,000 tons of alloy-steel. The steel which we have made from this slag is of excellent quality, but the nickel and copper contents are too low to make it a substitute for the standard 3% nickel steel, and it appears, therefore, that these slags can best be treated in combination with the roasted ore, thereby obtaining from the mixture a steel which will carry about 3% of nickel and copper in the proportions of 3 or 4 to 1.

There are many ores in the Sudbury District which do not contain the correct percentages of nickel and copper for the manufacture of 'Nicu' steel; in some cases the copper content is more than half the nickel content, and in a few cases the copper is as much, or even more than, the nickel. In the arts and industries, however, a large amount of nickel will always be needed for other purposes than steel making. At present,

about one-quarter of the entire nickel production is used for such purposes. Some of the nickel and copper becomes 'Monel metal,' which has many important uses; some of the nickel is used in making bronze, or for the manufacture of 'German silver'; some is used for coinage (either pure or alloyed with copper), and some for nickel plating where a very pure nickel is required. Thus, even if the 'Nicu' process should find general adoption, there would still be room for the treatment of ores which did not carry the correct percentages of nickel and copper and which would naturally be treated along the lines of the present metallurgical processes for the production of pure nickel, pure copper, or Monel metal. Even in the treatment of these ores the 'Nicu' process can serve as a valuable adjunct by treating the slags from the blast furnaces in combination with other ores for the manufacture of 'Nicu' steel, and in this way there would be practically no loss of nickel, copper, or iron from any of the ores.

The processes here described are covered by patents both in the United States and Canada, and these patents[9] are now owned by the Nicu Steel Corporation, Limited. Without recounting the numerous laboratory experiments and trial runs which have been made in the past, a brief account may now be given of the actual manufacture of steel under commercial conditions as recently carried on in East Montreal. Not wishing to go to the expense of opening up a mine prior to testing out the process, we purchased from the Algoma Steel Company, a quantity of low-grade ore which had been mined some 20 years ago, and had been weathering ever since, with the result that a considerable amount of the nickel and copper had been leached out, most of the sulphur had oxidized, and the ore had disintegrated to such an extent that it was almost a powder and did not require any crushing prior to roasting.

The average composition of the ore as received in Montreal was as follows: Iron, 46.0%; nickel, 1.30%; copper 0.28%; silica, 19.0%; and sulphur 8.0%. The ore was roasted in

[9] U.S. Patents 1106785, 1106786; Canadian Patent 149421 and 149874.

an improvised reverberatory furnace which had formerly been used for heating steel shells, rabbling was done by hand, coal was used as fuel, and without any great difficulty the sulphur was reduced to an average of .40%. The calcined ore was charged into an electric tilting furnace of the Heroult type with three vertical electrodes and a rated capacity of 6 tons of steel. This furnace was not ideal for the reduction of the ore, but no other was available, and everything considered, it served our purpose very well. The average furnace charge contained: 1400 lb. roasted ore; 525 lb. burnt lime; 375 lb. coke breeze or coal, and some steel filings were thrown in on top of the charge to start the electric current. After heating for a short time, another charge would be added until six or eight charges had been added. Unfortunately, a considerable amount of iron was also picked up from the bottom and sides of the furnace which had been used for a long time previously for making pig iron from scrap steel. Slag was poured off at intervals through the charging door by tilting the furnace, and the pig metal was poured from the opposite or tapping end of the furnace into a ladle and cast into slabs in the usual manner. The average composition of the pig was as follows:

Nickel	2.20%
Copper	0.40%
Manganese	0.18%
Silicon	1.75%
Carbon	3.0 %
Sulphur	0.09%
Phosphorus	0.07%
Iron (by difference)	92.41%

The slag produced from smelting the ore to pig metal contained 2.20% of iron and only a trace of nickel and copper, but in commercial practice it is safe to say that the iron content of the slag could be kept well below 1.0%.

The pig metal was subsequently refined, at first in the same electric furnace which had been used for the reduction of the ore,

and afterwards with better success in an open hearth furnace of standard type and following closely the practice of ordinary steel making. The average composition of the steel resulting therefrom was as follows:

	%
Nickel	2.13
Copper	0.40
Carbon	0.20
Manganese	0.51
Sulphur	0.03
Silicon	0.03
Phosphorus	0.006
Iron (by difference)	96.694

The slag obtained from the dumps at Copper Cliff was treated in nearly the same manner as described above, but without preliminary roasting and with slight modification of the flux. This slag had the following composition:

	%
Nickel	0.45
Copper	0.30
Iron	46.14
Sulphur	2.20
Silica	22.30
Alumina, Lime and Magnesia (by difference)	20.0

The steel, resulting from the reduction of the slag to pig metal and the subsequent refining in the open hearth furnace, had the following analysis, and it will be noted that the percentage of nickel was increased in proportion to the percentage of copper, presumably by 'salting' from the furnace, which had

just been used for the treatment of the higher nickel pig made from the ore:

	%
Nickel	1.33
Copper	0.46
Carbon	0.34
Manganese	0.63
Sulphur	0.041
Phosphorus	0.017
Silicon	0.019
Iron (by difference	97.163

During the trial operations above described, about 72 tons of steel were made from the ore and about 18 tons of steel from the slag. The steel is now being put to various commercial uses, while samples taken from the various heats have been submitted to physical tests, and similar samples have been submitted to the proper authorities and Commissions in both the United States and Canada to be tested for military purposes. The results of some of the tests which were performed on our behalf are given below, and for comparison are added the composition and requirements adopted by the British Government for automobile steel containing approximately the same percentage of nickel as the combined nickel and copper content of the 'Nicu' steel.

British Government Standard		Nicu Steel	
E. S. C. 2% nickel case-hardening steel			
Ontario Nickel Commission Report, p. 360			
Analysis—			
Carbon	0.10—0.15%	Carbon	0.20%
Manganese	0.25—0.50%	Manganese	0.51%
Sulphur	not over 0.05%	Sulphur	0.03%
Phosphorus	not over 0.05%	Phosphorus	0.006%
Nickel	2.0 —2.5 %	Noicke	2.13%
		Copper	0.40%

Physical Tests

Tensile.....(tons)	25 to 35	Tensile.....(tons)	31
Yield point not less than....	55%	Yield point.....	74.5%
Elongation not less than.....	30%	Elongation.....	35%
Reduction not less than.....	45%	Reduction.....	62.6%
Normalized at 850° C. to 900° C.		Forged natural.	

I also quote as follows, tests on various heats of the 'Nicu' steel produced and subjected to heat treatments as noted.

Nicu Steel Corporation, Ltd.

Tests on 'Nicu' Steel

		Tensile lb. per sq. in.	Yield lb. per sq. in.	Elongation 2" %	Reduction %
Forged	Heat 1	69,440	52,192	35.	62.6
Natural	Heat 4	67,648	50,848	35.	62.6
Heated to 1425° F. cooled with air	Heat 1	69,440	58,240	31.	55.
	Heat 4	70,560	58,240	30.5	55.
Heated to 1450° F. quenched in oil and re-heated to 800° F.	Heat 1	72,800	53,760	34.	55.5
" " " "	Heat 4	75,712	58,688	35.	55.
Heated to 1550° F. quenched in water and re-heated to 600° F.	Heat 1	85,120	64,288	28.	55.
" " "	Heat 4	84,670	69,440	28.	55.

Chemical analyses—

	Carbon	Silicon	Sulphur	Phosphorus	Manganese	Nickel	Copper
Heat 1	0.20%	0.03%	0.03%	0.006%	0.51%	2.13%	0.40%
Heat 4	0.28%	0.014%	0.038%	0.005%	0.58%	2.16%	0.41%

Nicu steel produced commercially at the Canada Cement Co. steel plant, East Montreal, and tested by Dr. Alfred Stansfield, in comparison with nickel-steel of similar composition as given in tabulated form on Page 387 and Page 416 Royal Ontario Nickel Commission Report:

	'Nicu' Steel Heat No. 6	Nickel Steel Page 387	Nickel Steel Page 416
Carbon	0.37%	0.47%	0.47%
Manganese	0.88%	0.86%	.....
Nickel	1.89} 2.26%	2.15%	2.92%
Copper	0.37}	.....	.....
Yield point	52,000 lb.	52,000 lb.	56,000 lb.
Tensile stress	96,500 lb.	93,000 lb.	95,400 lb.
Elongation on 2 inches	24.3%	24.5%	22%
Reduction of area	50.8%	51.8%	44.6%
Bending tests 180°.	Showing no crack	Showing no crack	

Physical tests and analyses of 'Nicu' steel Heat No. 6 made by Dr. Alfred Stansfield of McGill University in comparison with nickel-steel as per specification for plates and shapes, Ontario Nickel Commission Report, Page 365:

	Natural 'Nicu' Steel	Nickel Steel
Carbon	0.37%	0.45%
Manganese	0.88%	0.70%
Phosphorus	0.064%	0.04%
Sulphur	0.047%	0.04%
Nickel	1.89% } 2.26%	3.25%
Copper	0.37% }	
Tensile stress, lb. per sq. in	96,300	85,000 to 100,000
Copper	0.37% 2.26%	
Yield point, lb. per sq. in	56,350	50,000
Elongation on 9 in	18.7%	16.2%
Reduction of area	36.3%	25. %

Nickel steel specification in connection with the fabrication of the large bridge to span the Mississippi River at Memphis:

Tensile strength	85,000—100,000 lb.
Elastic limit not less than	50,000 lb.
Elongation in 8 inches not less than	1,600,000 Av'ge 17%
	Tensile Strength
Reduction of area not less than	30%

Results of the Royal Ontario Nickel Commission, Page 415, Table 3, from 'Nicu' Steel and nickel-steel produced under exactly the same conditions during their investigation of the Colvocoresses process:

	'Nicu' Steel Heat No. 2	Nickel Steel Heat No. 4	'Nicu' Steel Heat No. 6
Carbon	0.43%	0.53%	0.53%
Nickel	2.10% } 3.30%	3.43%	2.45% } 3.25%
Copper	1.20% }	None	0.80% }
Elastic limit	82,600 lb.	77,400 lb.	80,000 lb.
Tensile strength	110,400 lb.	115,400 lb.	111,600 lb.
Elongation on 2 inches	22%	20%	19.1%
Reduction of area	48%	38.3%	38.3%

These steels were produced under the direct supervision of Geo. A. Guess, Professor of Metallurgy, University of Toronto, in conjunction with the Royal Ontario Nickel Commission.

The following are extracts from Prof. Guess' Report:

"It is evident, from the results shown in Table 3, that these laboratory-made steels are of good quality."

"The value of this process of producing nickel-copper steel is based on the belief that copper may replace a very considerable amount of the nickel in a 3.5% nickel-steel, without producing an inferior article, which belief is, I think, well founded."

Tabulated data compiled from various sources by H. A. Morin, of Nicu Steel Corporation, Ltd.

	Analyses of Commercial Nickel	Analyses of Average Monel Metal
Nickel	99.10%	68.30%
Copper	0.03%	27.53%
Cobalt	0.40%	0.47%
Iron	0.30%	2.18%
Carbon	0.05%	0.05%
Sulphur	0.03%	0.04%
Silicon	0.05%	0.20%
Manganese	0.12%	0.14%

Physical Properties.

	Rolled Nickel Natural	Forged Nickel Natural	Rolled Monel Metal, Natural
Elastic limit	21,045 lb.	31,360 lb.	55,587 lb.
Tensile strength	72,522 lb.	72,128 lb.	88,232 lb.
Elongation in 2 inches	43.9%	45.5%	42%
Reduction of area	29%	57%	55%

	Copper Plates as rolled	Monel Metal Plates as rolled
Elastic limit	18,000 lb.	45,800 lb.
Tensile strength	34,000 lb.	90,000 lb.
Elongation in 2 inches	52%	30%
Reduction of area	57%	60%

The above figures show the physical properties of commercial nickel, pure copper, and a natural alloy of nickel-copper (Monel metal) manufactured by processes of concentration of the nickel-copper originally contained in the pyrrhotite ores of the Sudbury district.

While these results have been entensively published and are generally well known, I feel this comparison on the same page will prove of interest to show the superior physical properties of Monel metal over pure nickel and pure copper. This fact, to my mind, will serve to give further evidence that 3½% nickel-copper in like proportion added to steel will replace pure nickel in 3½% nickel-steel.

Royal Ontario Nickel Commission Report, Page 421. Comparison of 'Nicu' Steel with nickel-steel:

	'Nicu' Steel	Nickel Steel
Carbon	0.44%	0.46%
Silicon	0.034%	0.066%
Manganese	0.50%	0.70%
Phosphorus	0.013%	0.021%
Sulphur	0.013%	0.034%
Nickel	3.62% } 4.10%	3.36% } 3.46%
Copper	0.48% }	0.10% }

The Physical Tests of the rolled natural steels showed:

Elastic limit	72,400 lb.	74,624 lb.
Ultimate strength	115,000 lb.	122,000 lb.
Elongation in 2 inches	22%	16%
Reduction of area	51%	34%

In the annealed condition, the results were:

Elastic limit	63,750 lb.	64,750 lb.
Ultimate strength	107,300 lb.	119,000 lb.
Elongation in 2 inches	25%	17%
Reduction of area	48%	37.5%

The author has described the recent manufacture of steel in Montreal because it was the first 'Nicu' steel produced in a commercial manner by the 'Nicu' process, but the foregoing tables embody a number of tests conducted by different companies and individuals on 'Nicu' steel or the nickel-copper-steel, which, while similar in composition, was formerly made by different processes, and all of these tests, without exception, tend to prove that the 'Nicu' steel, or the nickel-copper-steel, is just as good as the nickel-steel which we hope, in a measure, to replace. In 1916, Dr. Stansfield of McGill University, at the author's request, experimented with the 'Nicu' process and made some excellent steel, and a little later Professor Guess, of Toronto, working under the direction of the Ontario Nickel Commission, also did valuable work along the same lines, and reports of their experiments, together with the tests made upon the steel produced, and on other similar steels, are embodied in the Report of the Royal Ontario Nickel Commission, which is altogether the most valuable treatise on nickel that has yet been published.

The author's experiments indicate that the best product is produced when the copper does not exceed one-third or one-quarter of the nickel contained in the finished product. In one experiment by the Ontario Government, a steel containing

nearly equal amounts of nickel and copper showed up very nicely in the mechanical tests; but the author's experience with steel of approximately this composition had not been very satisfactory, and he would not recommend any 'Nicu' steel in which the copper is in excess of 40% of the nickel, and would prefer a steel in which the copper was not more than 30% of the nickel; moreover, the copper content should probably not exceed 1% if the steel is to be used for the same purposes as nickel-steel. A great deal of nickel-steel as used at present contains 3% nickel, and we have found 'Nicu' steel containing 2.25% nickel and 0.75% copper is in all respects similar and equal to the nickel-steel mentioned.

The author will go a step further, and say that in some respects 'Nicu' steel is better than ordinary commercial nickel-steel, because it is a more homogeneous mixture and more uniform in composition. Nickel steel is made by adding nickel or nickel oxide to steel in the bath of the open-hearth furnace; thus the nickel is added in the final process of steel-making and is kept in combination with the iron, after melting, during a period of five or six hours. The theory of alloys teaches us that the nickel forms a solid solution with the iron, but it is a question just how complete and how uniform this solution can be made, and the problem that has confronted steel-makers has been to secure an alloy having a thoroughly uniform composition, and to prevent segregation in various parts of the resulting ingots. In the 'Nicu' process we calculate our charge and our alloy mixture before we smelt the ore into pig, and as far as possible the final percentage of nickel, copper, and iron is arranged for by mixing the ores before any smelting takes place, or during the first stages of the smelting. The sulphides or oxides of the three metals are then combined at the very outset of our operations, and the pig metal contains these elements in approximately the same proportion as the finished steel; the nickel combining freely with both iron and copper and never releasing them throughout the entire process. Perhaps, in a blast furnace or a shaft electric furnace, there would be times when the composition of the metal might not be entirely uniform, but such a condition is rectified in the refining furnace. The

final alloy-steel should therefore be of uniform composition and a more perfect mixture than ordinary alloy-steel made by the present methods, and so far as we have been able to determine this actually results from carrying out the 'Nicu' steel process. We feel that we have proved and are ready to prove again that 'Nicu' steel is a valuable alloy-steel; that it is not red-short or brittle, and that the copper contained in certain fixed percentages, relative to the nickel, acts just exactly like nickel and replaces the same quantity of a metal which normally sells for double its value. Aside from the mechanical qualities of the steel, there is every reason to believe that the addition of copper tends to render the alloy less subject to the action of acids, salt water, etc., and hence makes it especially valuable for shipbuilding, pump parts, and numerous other uses.

Clamer[10] experimented at considerable length on the effects of acids, salt air, and salt water on nickel-copper-steel made from Monel metal and found its resistance most remarkable, while the beneficial effect of the addition of small quantities of copper to ordinary steel has been known for a long time and taken advantage of by steel-makers to make special brands of non-corrodible steel for roofing and similar purposes.

We do not yet know how 'Nicu' steel will behave when utilized for armour plates or for many of the more important purposes for which nickel-steel is now employed; but judging from the fact that Monel metal steel made excellent armour-piercing projectiles, we believe that a 'Nicu' steel armour plate will be well worth trying out. We do not know how it will behave when rolled into rails, but from tests which have been made for other purposes, there is every reason to think that 'Nicu' steel rails will prove very useful and valuable, and if, as we claim, they can be manufactured at a cost only slightly greater than that of the ordinary steel rails, we think that there will be an immense demand in the future for 'Nicu' steel rails wherever the wear is unusually severe. So much for the quality of our product, which, so far as tests have proven up to the present time, we can truth-

[10] "Cupro-Nickel Steel", by G. H. Clamer, Proceedings of American Society for Testing Materials, Vol. X, 1910.

fully say appear to be equal to nickel-steel, but we must admit that the final value of 'Nicu' steel can never be determined until it is actually put into commercial use and tested out for various purposes in the arts and industries.

Now, let us turn to the cost of manufacture, and here I must theorize somewhat, since we have no actual experience from which to quote. Laboratory work, of course, has given no clue to actual manufacturing costs, and even our work in Montreal was carried on in a plant which could only be leased for a month for the purpose and where we operated under many handicaps and with many make-shift appliances; hence the costs of our manufacture form but little better basis for calculations than the work previously done in the laboratory. Let us, however, start with the mining of the ore, and assuming that we already have an orebody, we know that the ores of the Sudbury district can be mined on the average of $3.00 per ton, this being about the average cost attained in 1916. The cost of crushing, roasting and sintering we can justly compare with the cost of similar operations on copper or iron ores, and this may fairly be placed at an outside figure of $2.50 per ton. The roasted and sintered ore is practically in the same condition as an ordinary hematite iron, though the iron contained is lower than the average in most ores which serve commercial uses to-day, and the smelting cost is, therefore, comparable to the cost of smelting iron ores in the same locality, and provided a blast furnace is utilized, and assuming that it will require two tons of Sudbury ore, plus a small amount of pig iron or scrap iron, to produce one ton of pig metal, we figure liberally that our smelting costs will be about $12.00 per ton of pig, and the total cost of a ton of alloy pig will, therefore, be $23.00. In the open hearth the pig metal may be made into steel for the same cost as ordinary pig iron is refined to steel by this process, and our alloy-steel, allowing for general and overhead expense, therefore, would cost about $35.00 per ton. Now, if we mined an average grade of Sudbury ore, the results would be one ton of 'Nicu' steel, containing about 6% nickel and about 2% copper, which would be comparable to 8% nickel-steel; the percentage of nickel and copper is higher than would be required for most commercial

purposes, and by mixing, in the open hearth or in a blast furnace, the smelted ore with slag, or with ordinary pig iron, or scrap iron, the percentage of combined nickel and copper is reduced in reference to the iron, and the steel would contain about 2.25% nickel and 0.75% copper and would be equal to 3% nickel-steel. The total cost of manufacturing this 3% 'Nicu' steel figures as above at $30.00 per ton, assuming that slag is used and paid for at a reasonable price. The steel would cost $30.00 per ton if scrap iron were used and paid for at $16.00 per ton, or $40.00 per ton if pig iron were used and paid for at $30.00 per ton. These estimates may be compared with the selling price of 3% nickel-steel, which at the present time is upwards of $100.00 per ton and which in normal times would be over $60.00 per ton. No account is taken in these calculations of the possible profit which might result from the recovery of the sulphur and the sale of this valuable by-product.

The costs which I have given above will, I believe, stand careful analysing, although round figures have been used, and it is not my intention in this article to dwell at any great length upon the commercial aspects of this process. These, however, must be considered, since no process or method of manufacture can be considered successful unless it actually produces a valuable product at a profit to the manufacturers. We do not, of course, yet know just what the costs will be when operations are carried out on a large scale, but it seems as if there were sufficient data to make a very fair and conservative estimate and, unless the author is sadly at fault in some particular, the proposition would appear attractive from the financial as well as the metallurgical side. There remains the fact that such a process can only be worked satisfactorily by a company possessing a large supply of suitable ore, and, moreover, that a very heavy investment for plant and equipment would have to be made before proper working conditions could be established and operations carried on with economy and efficiency. Such operations must be undertaken on a large scale, which we believe will be amply justified by the large demand which should be established for a satisfactory substitute for nickel-steel, selling at a price far lower than nickel-steel can be sold

for at the present time. We have an iron mining and smelting proposition with the cost of ordinary steel making increased by the higher value of the ore in the ground, the higher cost of mining the Sudbury ore, the cost of roasting and crushing and sintering, and the increased cost of fluxing the larger percentage of insoluble matter. The operating costs of the blast furnace and the open hearth, or of the electric furnace if substituted for either or both of these, should be no greater than they are at present in ordinary steel practice, but instead of producing an ordinary steel we produce a high-grade alloy-steel which is far more valuable for many purposes than any ordinary steel; far superior in physical and mechanical qualities and commanding a price double that of ordinary steel, and this difference in price should amply compensate for the increased working costs enumerated above.

From the commercial standpoint, the claim is made that 'Nicu' steel is as good as nickel-steel and that the 'Nicu' process will enable the manufacturers to make such steel for a much lower price than nickel-steel can be made at the present time, and by the methods now in use, and considering the enormous demand for nickel-steel, and particularly the extra demand that would result from a material reduction in the price, 'Nicu' steel should find an ample market without difficulty.

From the metallurgical standpoint, we claim attention as presenting a new alloy, and a new method of manufacturing a ternary alloy and of treating an ore that has long constituted one of the most valuable resources of Canada.

From the standpoint of conservation, we offer a method that should provide for the profitable recovery and utilization of the enormous amount of iron that is now thrown away in the Sudbury district, and perhaps also of all the sulphur which is at present wasted, with no advantage to smelting companies and with more or less detriment to the agricultural industry of the neighbourhood.

It seems reasonable also to assume that the adoption of this process will permit the profitable mining and treatment of large deposits of ores low in nickel and copper content, but compara-

tively high in iron, which deposits must otherwise remain unworked.

The 'Nicu' process will not provide a means of recovering the precious metals (gold, silver, and the metals of the platinum group) occurring in the ore to the average value of 50 cents per ton (of which less than 40% is saved by present methods), but it can save 98% of the nickel against 80% saved by the present methods; 98% of the copper against 83% saved at present; 96% of the iron and probably 80% of the sulphur, both of which are entirely lost at present. Turning back to the figures quoted at the beginning of this paper and assuming the gross value of the useful metals in the Sudbury 1918 production to be $90,000,000, I repeat that metals to the value of only $44,000,000 will be saved this year, whereas the general application of the 'Nicu' process for ore and slag would result in the saving of metals with a value of $41,000,000 additional, making a total recovery of 94% against 49%, and with a very comfortable profit to the operators.

From the industrial standpoint, we claim attention as presenting a method of establishing a valuable new industry in the Dominion of Canada; an industry which may produce annually close to 600,000 tons of high-grade alloy-steel, largely from material now thrown away, or nearly 40% of the total steel produced in the Dominion at the present time, and a valuable alloy-metal which can be produced altogether or in great part in Canada, and which should fill an important place in the prosecution of the war; while after the war shall be happily and successfully ended, this alloy-metal should also be of continuous and equal value in the arts and industries of peace.

We are proposing something very radical—to upset the established practice for the treatment of the Sudbury ores—a practice which is as old as the discovery of the orebodies, which has been operated continuously and improved upon frequently, which has successfully accomplished its purpose and proved very remunerative to the operators. We are proposing to introduce into the industries a new alloy-metal to partly replace one of the most valuable and widely known alloys of steel; above

all, we are proposing to run counter to the prejudice against copper in steel which is far older than the discovery of the Sudbury mines and which still persists in the mind of manufacturers and users of alloy-steel, in spite of the fact that repeated experiments and actual performance have proved this prejudice unfounded. We realize fully that it will be an uphill fight to firmly establish this new industry, but we feel that our process rests on a sound metallurgical and commercial basis, we feel encouraged with the progress which we have made, and are very confident of our ultimate success, which will mean some very important changes in the mineral industry of Canada.

For the treatment of the many million tons of Sudbury ore still to be mined, we believe that our process alone will measure up to the standards of conservation and efficiency which are going to prevail in the future; for the most vital lesson of the present war is this: "The greatness of a nation does not consist in the possession of great natural resources, but in the efficient use which is made of them."

Discussion

Dr. Alfred Stansfield: I have listened with extreme and unusual interest to the valuable and revolutionary paper that has just been read, and it has brought to my mind some general considerations with regard to our Canadian industries. Since coming to this country from England, seventeen years ago, I have been struck repeatedly with the wasteful way in which Canadian resources are developed. When speaking of this the retort was always made that it is all business; that, for example, if you get a certain profit from recovering half the available material, and would obtain a smaller profit from recovering three quarters of it, it is better business to get the half. Recent events have gone far to change that idea. Mr. Colvocoresses and others have drawn our attention to the changed conditions, and we realize now that our somewhat vague feelings that it was not really right to waste our commodities and resources in

order to get good profits have really a firm foundation on an economic basis. We now realize that in utilizing any raw materials we should consider the value to the nation of the product we turn out and the industries we support, and only to a smaller degree the financial return to the corporation which advanced the funds and directed operations. We now look at these things from a somewhat broader point of view than we did, and in connection with most of our Canadian industries we must consider carefully to what extent the nation, as a whole, benefits in regard to economy of resources, employment of labour and technical skill, and financial reward to capital. It must no longer be considered that the financial return obtained for capital is the only measure of the goodness of the methods that are adopted. In view of these considerations I am sure that more attention will be given to this paper than it would have received at any time before the war. If the Colvocoresses process will give us additional products and provide more work to more men at larger wages and conserve the resources of the country, it would merit very careful attention, but if in addition to that additional profits can be earned, the process constitutes a very important step forward in the industries of the country. For the treatment of copper-nickel ores there are already large and well established industries, and it might be feared that these might be destroyed by the introduction of this new process. It will be found, however, that there is room for the existing companies as well as for the new process. The utilization of the sulphur in these ores has been dealt with by Dr. Wilson, and we shall look forward to further developments in that direction. It still remains, however, to ascertain whether this new nickel-copper steel can be used to replace nickel steel for all or many of the purposes for which it is employed. Many experiments have been made, but we all realize that steel making is very difficult and is a very delicate subject on which to make a final report. It is one thing to produce small quantities of steel and another thing to produce it commercially to replace the standard material. No one who is associated with the experimentation can presume to state definitely that this new steel will replace

nickel steel, but the evidence seems to indicate that it may to a large extent.

Dr. A. W. G. Wilson: As some of you are aware, the question of sulphur supply has been a hobby of mine for the last seven or eight years. We estimate from direct returns from consumers that we will have to import at least 125,000 tons of elementary sulphur in 1918. In addition to this we will use somewhere between 30,000 and 35,000 tons of pyrites. We will re-export about 60,000 tons of the imported elementary sulphur in a manufactured form. Last year we sent to the United States 126,000 tons of sulphur in pyrites and returned about 52,000 tons in manufactured form, the latter representing the sulphur used in manufacturing the sulphite pulp and newsprint paper that was exported to the United States. Just how much we can send back in manufactured form next year is uncertain. This year we expect to export at least 378,000 tons of pyrites containing 37% sulphur, and next year we should send them at least 400,000 tons.

I question if it is possible to condense sulphur dioxide into liquid form, put it into bottles, and ship it any distance for consumption in quantity in paper mills, and make the operations pay a profit. This was attempted some years ago in Germany. The bottles used were said to contain about five or six tons each, and two bottles were mounted on each railroad truck, but it is questionable if such operations would pay here.

Our paper manufacturers may be forced to do one of two things, either to obtain liquid sulphur dioxide, or to change their plants and use pyrites.

The possibility of recovering sulphur from sulphur-dioxide is a question of national importance. Within 150 miles of the Great Lakes, on the American side, they need about 300,000 tons of sulphur annually, and this year there is a market for about 400,000 tons within 500 miles of the Sudbury district.

It is stated that there will be a shortage of sulphuric acid. If proper railroad freight rates could be secured, the corporations

operating in the Sudbury region could make sulphuric acid and deliver it at a price which would not be much over one-half of the present cost of this acid. The principal difficulty, which has prevented the development of sulphuric acid works in the Sudbury region, has been the cost of shipping the finished acid over the railroads. It is hard to say why the rate on this commodity should be higher than that on petroleum. This matter is to be referred to the War Trade Board with the suggestion that it be investigated. If we can obtain an adjustment of rates it may be possible to obtain additional supplies of sulphuric acid from the Sudbury district. Naturally the smelters cannot be expected to install roasting furnaces and acid plants if they cannot see their way clear to recover their capital.

If we could make elemental sulphur from these waste gases, or make sulphuric acid, Canada would command the sulphur or acid situation in the northern half of the continent.

Prior to the war the market price of sulphur was $20 per ton, f.o.b. docks, Galveston. Taking this statement that there are 300,000 tons of sulphur lost in the Sudbury region annually, this loss represents at least $6,000,000 per annum, part of which is recoverable. The September quotations were $46 per ton, and to-day they are higher, so the present value of the daily losses are higher and will probably continue to be so for some time. The importance to Canada of the development of a commercial method of recovering elemental sulphur from our waste sulphur dioxide gases must be obvious.

Dr. W. L. Goodwin: The last speaker has summed up the situation well in his final remarks. Dr. Stansfield has also referred to the wasteful methods we employ in using our resources. In this we imitate the chipmunk. It is well known to those acquainted with the habits of these little animals that when they get an unusual chance at corn, for example, they will carry it off and store away bushels—ten times as much as they can use in two or three seasons—and much that they so store goes to waste. I think, with Dr. Stansfield, that the author of this paper has indicated one way in which one very

valuable resource may be utilized to better advantage and to more profitable account. As a chemist I am particularly interested in the utilization of the sulphur from the Sudbury ores. It was contended a number of years ago, when the subject of saving the sulphur by the manufacture of sulphuric acid was urged, that the amount of sulphur oxidized in the roast heaps in the Sudbury district was so enormous that if we made it into sulphuric acid we would flood the market and it would not pay. I don't know whether those conditions could still be urged or not, but there is an increasing call, which will continue to increase, for sulphuric acid, for sulphur dioxide, and sulphurous acid. The production of such acids is the starting point for the foundation of so many industrial processes that if the sulphur in the Sudbury ores could be thus utilized and the product sold at a low enough figure, it might, and doubtless would, lead to the establishment of many subsidiary industries which at present cannot be profitably undertaken in Canada. Meanwhile there appears to be only one possible weak point in the Colvocoresses process, and that is, it makes no provision for the recovery of the precious metals—platinum, etc.—but that is so insignificant a factor in the situation that I do not think it needs to be considered.

GENESIS OF THE SUDBURY NICKEL-COPPER ORES AS INDICATED BY RECENT EXPLORATIONS*

By Hugh M. Roberts and Robert Davis Longyear,
Minneapolis, Minn.

(Annual Meeting, Montreal, 1918)

During 1916 and 1917 the E. J. Longyear Co., of Minneapolis, Minn., carried out a campaign of exploration for nickel-copper ore in the Sudbury District of Ontario. The work was

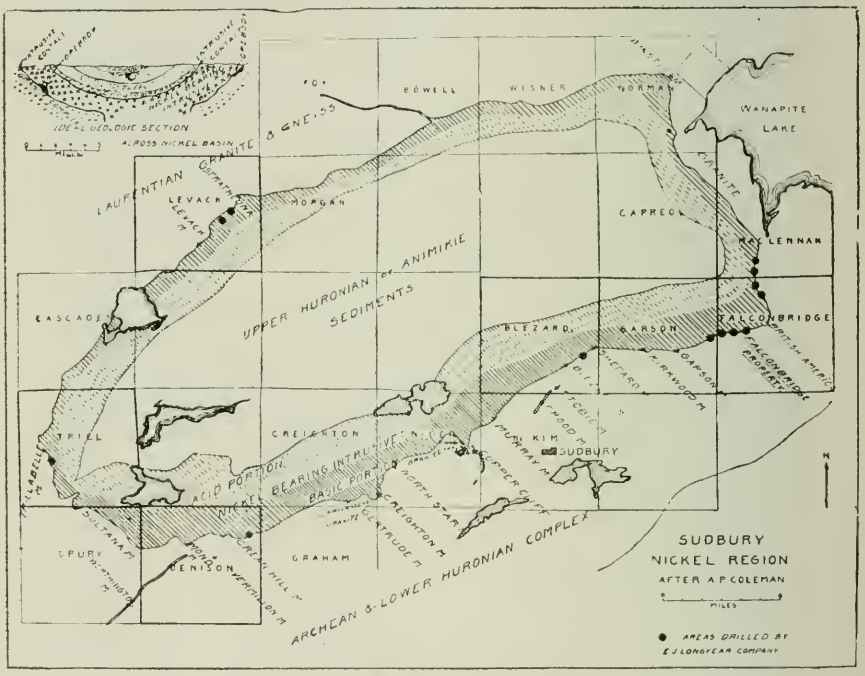

Fig. 1.—Sudbury Nickel Region.

initiated by W. E. Smith, a resident of Sudbury, who called the attention of W. J. Mead, Chief Geologist of the E. J. Longyear Co., to the fact that explorable lands in the Sudbury District were still available. Five diamond drills were employed, and holes were drilled in the townships of Levack, Trill, Denison, Blezard, Garson, Falconbridge, and MacLennan. The general map of the District, Fig. 1, shows the distribution of the lands chosen.

* Published jointly by the Canadian Mining Institute and the American Institute of Mining Engineers.

As a result of this exploration, a large body of nickel and copper ore has been found in the western part of the Township of Falconbridge. This property lies in the eastern part of the Sudbury District, east of the Garson mine.

The geological direction of this work necessarily included a careful consideration of the nature and mode of occurrence of the Sudbury ore deposits and of the various existing ideas as to their manner of origin. Since exploratory work is very practical research in the theory of ore deposition, the writers propose in this paper to present the results of this investigation, and in particular to trace the influence of current theories of origin of the ores upon the conduct of the exploration.

The field geology is discussed by H. M. Roberts; the petrography and detailed study of the ore is the work of R. D. Longyear.

We are indebted to C. K. Leith, W. J. Mead, W. H. Emmons, E. C. Harder, and others, for suggestions and criticisms.

General Geology

The various places where drilling was to be undertaken were selected on the basis of A. P. Coleman's[1] map and report. This was essentially the latest expression of the thought of Canadian geologists on the Sudbury District, embodying not only Coleman's own more recent work but the previous work of Barlow,[2] Walker,[3] and others of the Canadian Geological Survey and the Ontario Bureau of Mines. Attention was given also to the work by Dickson,[4] Knight,[5] and others, concerning the origin of the ore, whose views differed somewhat from those of earlier investigators.

[1] A. P. Coleman: The Nickel Industry with Special Reference to the Sudbury Region, Ontario. *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

[2] A. E. Barlow: Report on the Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of Sudbury, Ontario. *Canada Geological Survey, Annual Report* (1904), 14, Part H.

[3] T. L. Walker: Geological and Petrographical Studies of the Sudbury Nickel District. *Quarterly Journal of the Geological Society of London* (Feb., 1897), 53, 40-66.

[4] C. W. Dickson: The Ore Deposits of Sudbury, Ontario. *Trans.* (1904), 34, 3-67.

[5] Wm. C. Campbell and C. W. Knight: On the Microstructure of Nickeliferous Pyrrhotites. *Economic Geology* (1907), 2, 351-366.

It will not be necessary to enter upon a protracted description of the general geology of the district, as this has been discussed at length in recent geologic literature, but it may be well to outline a few important field relations.

Coleman's map shows a nickel-bearing intrusive, probably of Keweenawan age, which came in as a 'laccolithic sheet' or sill. We wish to state our belief in the essential accuracy of this map. The laccolithic sheet is a body some 10,000 ft. (3048 m.) thick and was intruded along an unconformable plane of contact between an older complex of Archean-Huronian rocks, and the younger flat-lying sediments mapped by Coleman as upper Huronian but described later by Collins[6] as Animikie.

During the intrusion and cooling of this mass, the flat-lying sediments of the Animikie were displaced, and deformation of all the rocks in the area took place. The crust of rock covering the internal reservoirs, from which the intrusion came, ultimately settled, so that at present the central portion of the district is folded into a synclinal basin some 40 miles (64 km.) long and 15 miles wide. A great thickness of Animikie sediments has been removed, and also much of the nickel-bearing intrusive itself, bringing the lower portions to view at surface. The distribution of the intrusive is oval-shaped, and its outer edge constitutes the outer rim of the basin. The sediments in the interior of the basin have been faulted and continuations of these faulted zones, exterior to the basin, are represented by bodies of norite which were intruded into zones of weakness. These masses constitute forms described by Coleman as 'offsets.' Typical instances are found at Worthington and Copper Cliff.

Since the time when the magma was hardened into rock, many geologic periods have elapsed. During this interval, the region has been planed down by erosion. In much of the area, all of the rocks are stripped down to the older complex which is itself eroded. The region has since been glaciated.

The nickel-bearing intrusive is composed of two kinds of

[6] W. H. Collins: The Huronian Formations of Timiskaming Region, Canada. *Canada Geological Survey, Museum Bulletin*, No. 8 (1914).

rock which grade into each other, micropegmatite, a phase of granite, in the upper portion, and norite, a species of gabbro, toward the bottom. This gradation has been called in question—notably by Harker.[7] At the very bottom of the intrusive, at its contact with the lower complex as now exposed by erosion, the norite and adjoining rocks contain the iron sulphide, pyrrhotite, with which is associated the nickel-bearing sulphide, pentlandite, and the copper-bearing sulphide, chalcopyrite. Commercial orebodies are found in places where the sulphides form a preponderant part of the rock. Orebodies of this type are described by Coleman as 'marginal' deposits. The 'offsets,' previously mentioned, also carry important orebodies.

We believe, after examining many widely scattered cross-sections, that the intrusive sill is essentially one geologic body, differing in its mineral content from place to place. There are, however, later intrusions of diabase. An intrusion of granite also occurs within the norite near the Murray mine. Toward the interior of the basin, *i.e.*, away from the lower contact of the intrusive, the norite changes its mineralogical characteristics and approaches granite in composition. This is true wherever the rock has been traced away from the contact in the Townships of Levack, Bowell, and Wisner on the north, Trill on the west, and Garson and MacLennan on the east. The more acid rock which is found is similar in grain, and can always be recognized as a part of the same mass as the basic norite at the edge. In large outcrops of the intrusive, the effect of segregative tendencies in the molten mass may be witnessed; areas, 20 ft. (6 m.) square, or more, may be seen to be dominantly composed of pyroxenes. At a distance of 100 ft., segregations of rock comprised more largely of plagioclase and orthoclase feldspars may be seen. These occurrences are physically continuous and have a continuity of texture and grain. During the course of a single drill hole, for instance, one deep hole drilled in the Township of Levack on the north side of the basin, the gradation in the mineralogical composition from basic to acid may be clearly recognized. These facts lead to the conclusion that the intrusive body is

[7] A. Harker: Differentiation in Intercrustal Magma Basins. *Journal of Geology* (Sept.–Oct., 1916), 24, 555–558.

essentially one mass, solidifying from a molten magma as a unit. The constant and widely distributed relation between the basic and acid portions of this body leads to the same conclusion.

We agree with Coleman that this mass is a sill, or laccolithic sheet, rather than a dike-like intrusion, for the reason that an inward dip from the contact toward the centre has been found at every place where we have drilled—in Levack 45°, in Trill 30°, in Denison 45°, in Falconbridge 70° to 90°, coinciding in this respect with the evidence at most of the mines. The instances of steep and southward dips of the contact on the south limb in Falconbridge Township and at Garson and Crean Hill mines might be accounted for on the basis that the structurally weak sediments and greenstones of those localities yielded under the weight of the intrusive and rolled up before the advancing mass, whereas the more resistant granite, as at Creighton mine, withstood the thrust; hence the relatively flat dips wherever the footwall is composed of massive granite.

THE OREBODY IN WESTERN FALCONBRIDGE TOWNSHIP

The orebody, here described, is located in Lots 10, 11 and 12 of the Fourth Concession of the Township of Falconbridge. As is shown on the accompanying maps, Fig. 1 and Fig. 2, it lies at the eastern end of the southern limb of the synclinal basin, occurring at the outer margin of the norite. The Garson mine of the Mond Nickel Co., 2½ miles to the southwest, is the nearest productive orebody. East of the property, in Lot 8, Con. IV, is a prospect owned by the British-America Nickel Co., where a small tonnage of medium-grade ore has been developed.

The main orebody is shown on the map, Fig. 2, and has a length of 7500 ft. (2286 m.). The exploration was done mainly by diamond drilling. A small exploration shaft was sunk in ore for the purpose of checking the results of the drilling.

A mantle of glacial drift, from 50 to 250 ft. (15 to 76 m.) thick covers most of the rock formation. The few rock outcrops which occur near the norite contact are shown in Fig. 2. In the main, the drift has formed extensive sand plains broken in

places by kettles, locally known as *pot holes*. Cutting diagonally across the western part of the property in a northeasterly and southwesterly direction is a peculiar series of kettles, hills, and ridges, which extend northeastward to Wanapitei Lake (Fig. 1).

The general inclination of the bed-rock surface is southeastward toward an old pre-glacial valley now indicated by swamp land, and small lakes. As shown by drilling, there is a rock escarpment along the northwest shore of Boucher Lake over which the glacial material has spilled, forming a steep bank.

QUARTZITE-GRAYWACKE FORMATION[8]

The quartzite-graywacke formation shown on the map, Fig. 2, is the oldest of the three formations present in the vicinity of the orebody. It is part of a group classified by Coleman as pre-Huronian, and called the Sudbury series. Miller and Knight refer to it as the Timiskaming series. It has a dip of about 90° and strikes about North 80° east.

In this vicinity the formation is composed of about equal proportions of quartz grains and altered ferromagnesian minerals. In some parts the quartz is in excess, and the rock grades toward a true quartzite; while in others the ferromagnesian minerals predominate, giving a more typical graywacke. Some phases of the formation have a marked schistosity approximately parallel to the bedding.

GREENSTONE

The greenstone is assigned to the Sudbury series by Coleman. It is a fine-grained, altered basic igneous rock composed essentially of amphibole and chlorite probably intrusive into the sediments.

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[8] For a general description of the Sudbury rocks see:

A. P. Coleman: The Sudbury Nickel Deposits. *Ontario Bureau of Mines* (1903), 12, 235–303. The Nickel Industry with Special Reference to the Sudbury Region, Ontario; *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

A. E. Barlow: Report on the Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of Sudbury, Ontario; *Canada Geological Survey, Annual Report* (1904), 14, Pt. H., also reprint *Bulletin* 96 (1907).

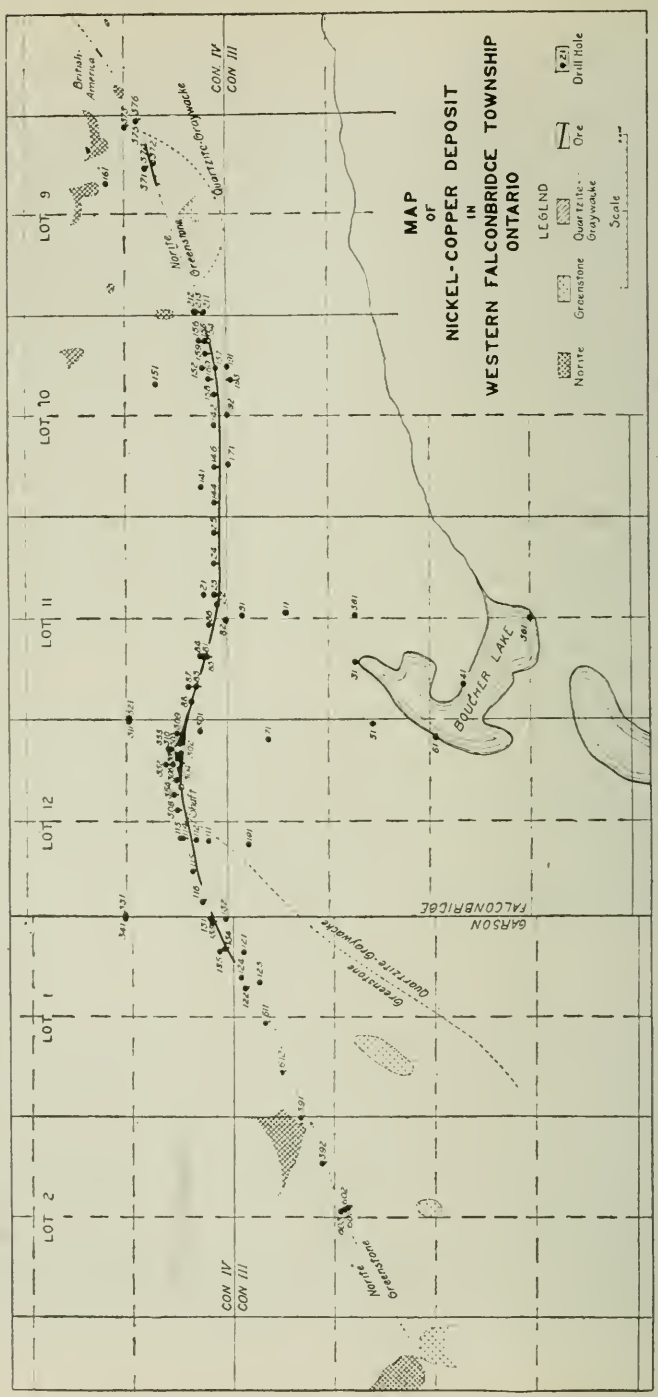

Fig. 2.—Map of Nickel-Copper Deposit in Western Falconbridge Township, Ontario.

In places, it has developed considerable schistosity. It is everywhere cut by intersecting quartz veins varying in size from minute stringers to veins a foot or more in width.

NORITE

The term norite is here used to include all phases of the great Sudbury laccolith within the area here discussed. These phases are: (1) subordinate amounts of typical unaltered quartz-norite containing hypersthene and quartz; (2) altered norite in which the pyroxenes have been altered to amphibole, making up the greater part of the formation; (3) spotted norite, or altered norite containing blebs of sulphides, occurring as a narrow selvage near the base; (4) minor amounts of granitic material and more acid phases of the norite, found usually near the margin.

Throughout the district, the lower contact of the norite generally has a dip of about 45° toward the centre of the basin, but in Falconbridge Township and a few other places it stands nearly vertical, or even overhangs. The norite thus usually forms the hanging wall of the orebody, and the older rocks the footwall.

Wherever fresh specimens of norite have been obtained in the Sudbury district, the rock has been found to consist mainly of hypersthene, augite, plagioclase, biotite, and quartz. In most places, the rock has suffered considerable alteration which has changed the pyroxenes to hornblende and uralite. The plagioclase usually has the composition of labradorite.

In the Falconbridge norite, the plagioclase is more acid and varies from Andesine (ab_3an_2) to andesine-oligoclase (ab_3an_1). The pyroxenes have disappeared almost entirely, having been replaced by hornblende, uralite, chlorite, and serpentine. A small amount of olivine was noticed in one slide. Quartz occurs as original grains filling the spaces between the other minerals, and also as a fine-grained secondary product of dynamic metamorphism. In hand specimens, the quartz generally has the blue colour which is so characteristic of the Sudbury norite. Considerable brown biotite is always present.

A few hundred yards north of the southern contact or base, in Garson and Falconbridge Townships, the norite becomes more

acid. Orthoclase feldspars are visible, and there is an increase in the amount of quartz, with a decrease in the amount of ferromagnesian minerals. The quartz is no longer blue. To the north, the rock takes on a more reddish colour, and in about 1½ miles passes into micropegmatite containing plumy intergrowths of quartz and feldspar.

Blebs of pyrrhotite and chalcopyrite are visible in the norite along the contact in the vicinity of the ore, but they are seldom found more than a few hundred feet from the contact. The mineral pentlandite, which is associated with the pyrrhotite, can seldom be detected except in a polished section or by etching. The sulphides are later than the silicates, and in many cases replace them. This does not necessarily mean that they were introduced in place later than the intrusion of the norite, but that they *crystallized* later than the silicates. A very common occurrence of the sulphides is in association with biotite, pyroxene, or hornblende, where they usually are found in stringers parallel to the cleavage. This relationship does not seem to occur in the case of the uralite.

Minor amounts of apatite, magnetite, and other accessory constituents are present.

The only rock in this vicinity which has been found to contain hypersthene is a dark basic rock occurring in the midst of a more acid type about 300 yd. north of the contact, in Lot 2 of Garson Township. It is one of the more basic phases of the norite mass which has suffered less alteration than the other parts.

There is a considerable amount of acid material scattered throughout the base of the norite. In places it is a typical granite, although often it resembles the norite except that it has a larger percentage of quartz and acid feldspars. It has been observed in several of the drill holes, and as irregular patches in outcrops of norite in eastern Garson Township.

The granite material is probably a local segregation phenomenon, and cannot be called a later dike, or included footwall rock. The nearest known granite in the footwall is several miles distant. The contact between the granitic material and norite is seldom sharp, but usually gradational. This gradation is not

in the nature of a 'reaction rim,' but is very irregular and obscure. One drill hole showed a gradual transition from granite into norite through a distance of 3 ft. (0.9 m.) in which the change took place by a simple decrease in the quantity of alkali feldspars and quartz and an increase in the basic feldspars and ferromagnesian minerals.

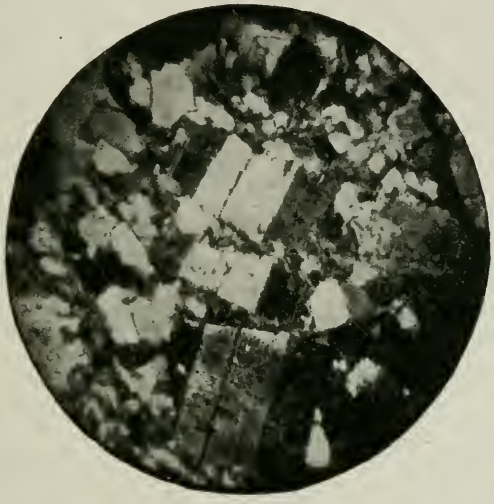

Fig. 3.—Photomicrograph of Fracturing in Feldspar Crystal.

METAMORPHISM

All of the rocks show evidence of having suffered metamorphism. This is especially marked in the older footwall rocks, where the sediments have become quartzite, quartz schists, graywacke schists, etc., and where the basic intrusives have been altered to more or less schistose greenstones.

The norite also shows signs of metamorphism, consisting mainly of the alteration of the pyroxene to hornblende, uralite, and chlorite, with a local development of schistosity. The schistosity is more marked near the contact, where it is sometimes very difficult to tell whether the rock is norite or footwall. Minute fracturing of the rock-forming minerals can also be

observed in places. This is well illustrated by Fig. 3, showing a crystal of feldspar fractured by a number of parallel planes. The fractures are filled with secondary quartz and sericite. This type of fracturing has been described by Howe[9] as occurring at the Frood mine.

It would be extremely difficult to attempt to outline a definite historical sequence of the various stages of metamorphism. Tolman and Rogers[10] believe that there was a definite order of mineral formation in the norite, this order being (1) silicates, (2) magmatic alteration of pyroxene to hornblende, (3) ore minerals, (4) hydrothermal alteration products.

From our studies, however, it does not appear as if the succession is as definite as this. We are not convinced from the evidence presented that the sulphides are later than the hornblende. The possibility is still open, that the hornblende is later than the sulphides, for it is simply an alteration product of a previously existing mineral. It is stated that the tremolite is definitely later than the sulphides. No doubt this is to some extent true, since some such alteration is probably in continual operation in all rocks. And yet, in the case of the Falconbridge norite, crystals of hornblende can be seen which grade into a more fibrous uralite (probably similar to the tremolite observed in the slides studied by Tolman and Rogers) and are probably formed at the same time as the uralite.

It seems probable, in the case of the Falconbridge norite, at least, that hornblende was formed *both before and after* the introduction of the ores; and that *most* of the fibrous amphibole has been formed since the ores. At present, we cannot determine a more accurate sequence.

THE OREBODY

As indicated in Fig. 2, the orebody occurs at the contact of the norite and footwall in a continuous band extending from the

[9] Ernest Howe: Petrographical Notes on the Sudbury Nickel Deposits; *Economic Geology* (1914), 9, 505–522.

[10] C. F. Tolman, Jr., and A. F. Rogers: A Study of the Magmatic Sulphide Ore; *Leland Stanford Junior, University Publication*, University Series (1916).

southwest corner of Lot 12, Con. IV, to the southeast corner of Lot 10, Con. IV, in the Township of Falconbridge. This is a total length of 7500 ft. (2286 m.), which is longer than any other known orebody in the district. This length has not been completely explored throughout, but it is a reasonable assumption that the ore is continuous over this length. Beyond the ends of this orebody are smaller outlying deposits (see Fig. 2), making the total length of the mineralized zone some 11,200 ft. (3413.76m.). The thickness varies from a minimum of 10 ft. (3 m.) to a maximum of about 120 ft. (36 m.). The greatest depth at which the orebody has been cut by a drill hole is 1020 ft. (310.9 m.) below the surface of the ground. It probably extends to a much greater depth.

This orebody is a typical example of the so-called *marginal deposit* of the Sudbury district. In general, the ore is at the contact of the norite hanging-wall and the underlying quartzite or greenstone, as is shown in Fig. 4. In some cases, however, the ore is several feet away from the contact, and within the quartzite or greenstone. This type is illustrated by Fig. 5. The ore generally dips steeply to the north. In two places, overhanging dips to the south have been observed. In some places the walls have a very irregular shape.

The ores can be classified in three types: (1) norite partly impregnated with sulphides, (2) footwall (usually quartzite on this property) partly impregnated with sulphides, and (3) massive sulphides containing small particles of rock. The last type grades into the other two.

The sulphides in the norite usually take the form of blebs scattered uniformly throughout the rock. The sulphides in the footwall rocks may be blebs, but are more often in the form of irregular veinlets. Often the rock associated with the ore is so schistose that its original nature is uncertain.

In the massive ore, it is rare to find less than 5 to 10 per cent of rock particles present. These particles may consist of quartz, norite, quartzite, greenstone, or an indeterminate schist. They may be rounded, subangular, or angular, and generally suggest replacement by the sulphides.

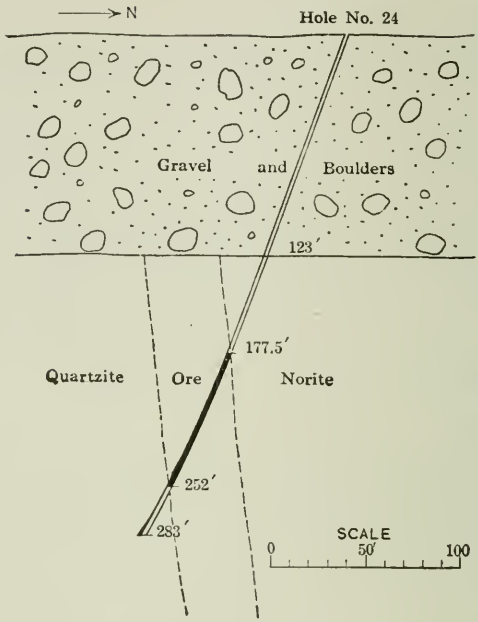

Fig. 4.—Cross-section of Drill Hole No. 24.

MINERALOGY

The sulphide minerals comprising the ore are, in order of abundance, pyrrhotite ($Fe_{11}S_{12}$), pentlandite ($FeNiS_2$),[11] and chalcopyrite (CuFeS).

The proportions of minerals present are shown graphically in Fig. 6. The first column represents the composition of a sample of typical mineralized or 'spotted' norite. Each of the other columns represents a composite sample of all ore in a drill hole between the foot and hanging walls. The relative amount of minerals present was calculated from the analyses given in Table 1, page 99. It was assumed that all of the nickel occurs in the form of pentlandite. Cobalt and arsenic were neglected as being too insignificant in amount to affect the results.

[11] This formula corresponds approximately with analyses made of the pure mineral pentlandite of the Sudbury district, although pentlandite from other localities sometimes shows less nickel and more iron. C. W. Dickson: The Ore Deposits of Sudbury. *Trans. A.I.M.E.* (1904), 34, 21.

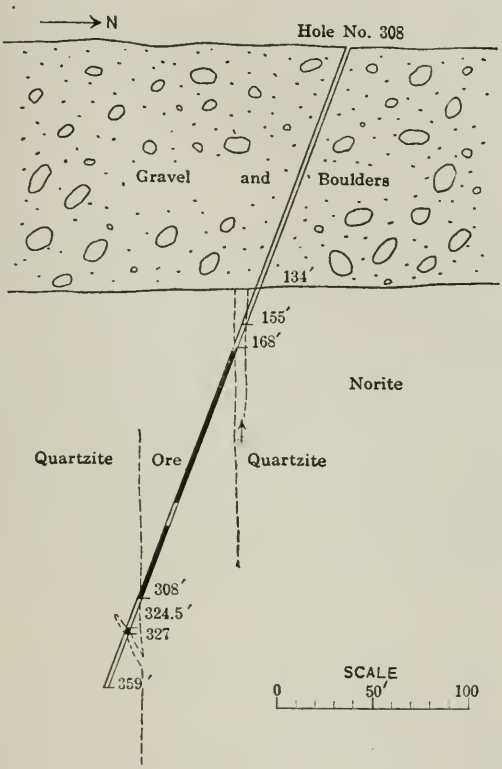

Fig. 5.—Cross-section of Drill Hole No. 308.

It will be seen that a very large proportion of the lode material is rock. It is customary in Sudbury mining practice to remove part of this rock by hand picking. The rest could be easily removed by flotation or some other mechanical process; however, a certain amount of siliceous gangue is necessary in order to act as a flux in the furnace for removing the iron. The rock gangue consists of quartz, or any of the country rocks or their altered equivalents. Calcite is rarely found.

The amount of chalcopyrite present seems to bear little relationship to the amount of rock, being as abundant in the rocky ores as in the richer ores. Pentlandite, on the other hand, increases as the amount of rock decreases, and bears a fairly

constant ratio to the amount of pyrrhotite present. Fig. 7, showing the analysis curves for copper, nickel, and combined copper and nickel, illustrates the same features. The 'copper curve' has practically no slope from left to right (rocky to less rocky ores), while the 'nickel curve' rises toward the right.

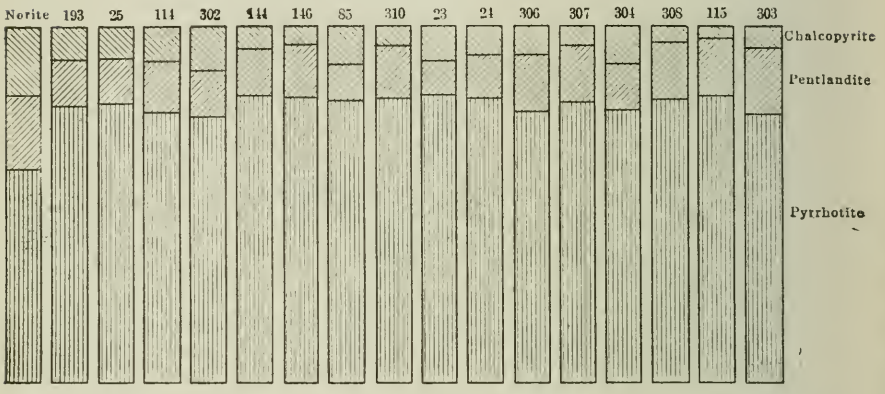

Fig. 6.
Graphic representation of the Relative Amounts of Sulphides and Rock Gangue in several Drill Holes.

A striking feature of this diagram is the complementary nature of the copper and nickel curves, maximums on the one curve being opposite minimums on the other, showing that where the copper is more abundant the nickel is less abundant.

Fig. 8 shows the ores of Fig. 6, recalculated so as to represent what would be the composition of the sulphides alone if the rock were entirely removed. The remarkable uniformity in the

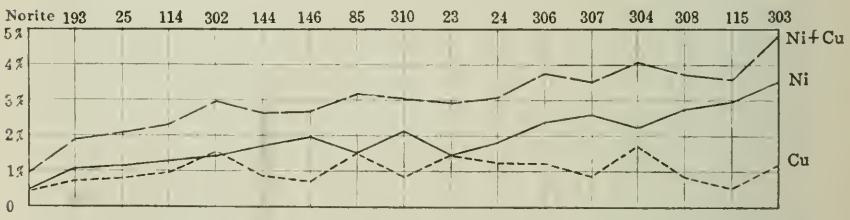

Fig. 7.
Curves showing the per cent of Nickel and Copper in the Ore of several Drill Holes.

composition of the ore is at once apparent. The chalcopyrite is the most variable member; the pentlandite is somewhat more constant; while the pyrrhotite, except in the first column (hanging wall), is invariably around 75 and 80 per cent. The bearing that this feature has upon the problem of the genesis of the ores will be discussed later.

Fig. 9 shows graphically the metallic content of the pure sulphide samples represented by Fig. 8. This indicates that pure sulphide concentrates of the ores, if made, would have

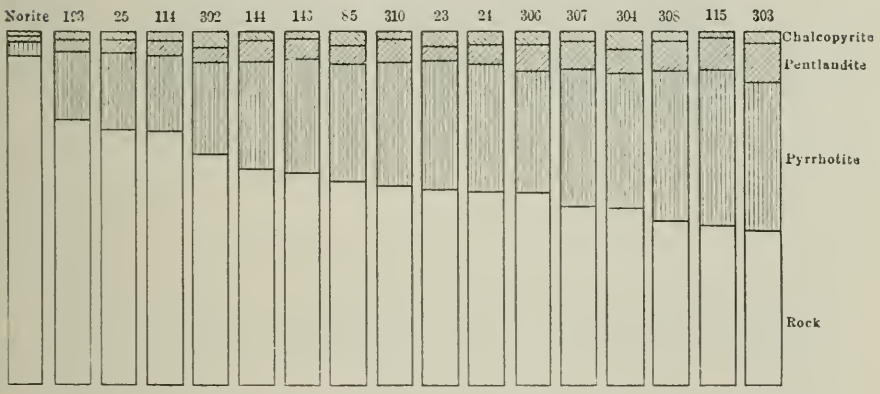

Fig. 8.
Graphic representation of Relative Amounts of Sulphides in the Ore of several Drill Holes.

practically a uniform content of 7 to 8 per cent combined metals. In the hanging wall, however (first column), where the processes of mineralization would naturally be more erratic, the sulphide concentrates would have a combined metallic content of 13.42 per cent. This suggests the possibility of a commercial exploitation of the 'spotted norite' in the not far distant future, when the present ore reserves have been exhausted.

The order of crystallization of the sulphides is (1) pyrrhotite, (2) pentlandite, (3) chalcopyrite. A photomicrograph of a polished section of the ore is shown in Fig. 10. The pentlandite (white) occurs as irregular masses and veinlets within the pyrrhotite (light gray). The dark material is the silicate

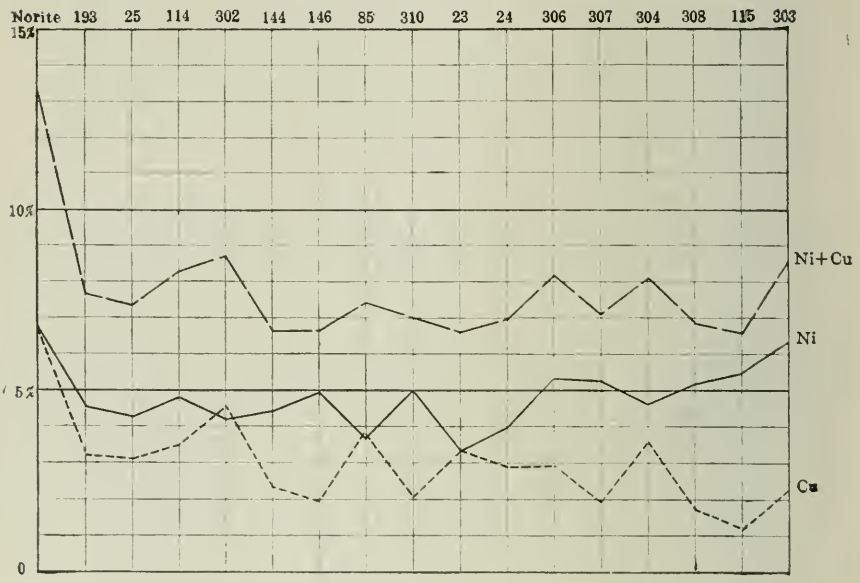

Fig. 9.
Curves showing what would be the per cent of Nickel and Copper in the Ore of several Drill Holes if all of the Rock Gangue were removed.

gangue. A patch of chalcopyrite (dark gray) can be seen between two masses of gangue. The ratio of pentlandite to pyrrhotite is generally somewhat less than is indicated in this photograph. The sulphides are later than the silicates.

The fact that the chalcopyrite is relatively more abundant with respect to the other sulphides in the rocky ores than in the richer ores can be explained, possibly, as follows: Although all of the sulphides were deposited from the same melt—or, more properly, solution—yet they were deposited in a regular order. The pentlandite was deposited later than the pyrrhotite, but followed it so closely that they are very intimately associated with each other and occur in a nearly constant ratio. The deposition of the chalcopyrite, on the other hand, seems to have been retarded somewhat, for its occurrence is very irregular. The solid masses of pyrrhotite and pentlandite did not allow the chalcopyrite to penetrate them to any extent, so it was forced

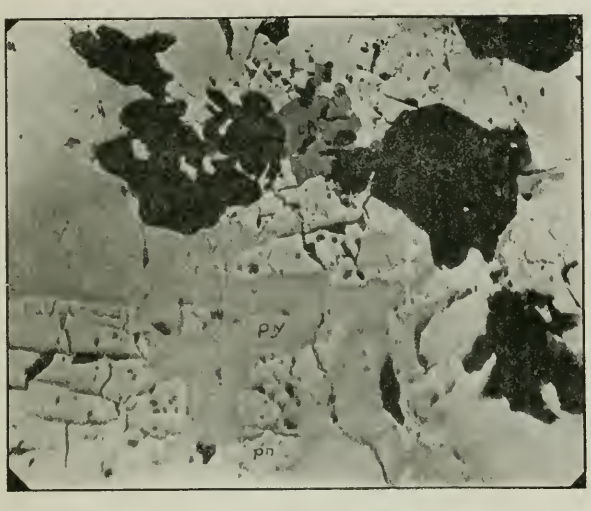

Fig. 10.
Photomicrograph of a polished section of the Ore.
Py, Pyrrhotite; *Pn* Pentlandite; *Ch*, Chalcopyrite.

to lodge in the channels formed between the pyrrhotite and rock particles. Also, being more soluble, it was able to migrate further into the rock. Thus the solid masses of pyrrhotite contain less copper than the rocky ores.

Magnetite is present in the ore in small amounts, but its period of formation has not been determined. Pyrite has been observed in some of the core, but the amount is negligible. It appears to be later than the other sulphides. In one place, a narrow band of galena was found cutting the mineralized norite. It is clearly a later introduction, and not directly connected in origin with the orebody. Aside from these no other sulphides have been detected, although a detailed study would undoubtedly disclose the presence of some of the rare nickel minerals such as polydimite, gersdorffite, etc.

GRADE OF ORE

During the course of the drilling, 90 to 95 per cent of the core was recovered. When in ore, this core was split longitudinally

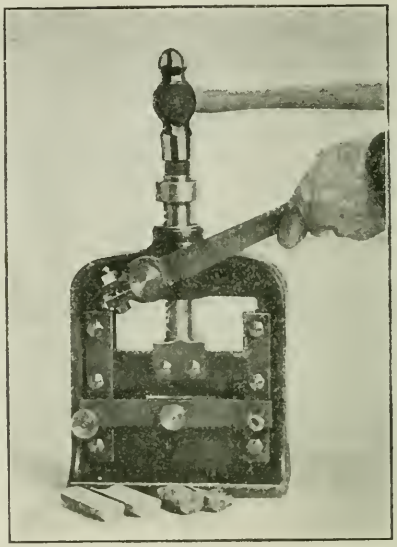

Fig. 11.

'Core-splitter' devised for splitting drill core before analyzing in order to preserve a complete sample of the ore without interfering with the accuracy of the analysis.

by means of a 'core-splitter' devised for the work, Fig. 11. One half was kept on file as a record of the physical characteristics of the ore, and the other half was ground for analysis. In uniform ore, intervals of 5 ft. (1.5 m.) were analyzed. In mixed ore and rock the division points were chosen according to the character of the material; but in no case was a smaller interval than 6 in. (152.4 mm.) analyzed, nor a greater interval than 5 ft. About 600 samples were thus analyzed. The determinations made were nickel, copper, iron, sulphur, and silica, with occasional tests for gold, silver, and platinum. The analyses were made by the Minnesota Testing Laboratories, Inc., of Duluth, Minn.

The content of the ore varies from 2 to 5 per cent in combined metals. The nickel content is fairly uniform in the massive ore, usually running about 2.5 to 4.30 per cent. The copper content is very irregular and ranges from 0 to 5 per cent with occasional higher values.

Composite samples of the ore in 16 of the drill holes were prepared and sent to Ledoux & Co. of New York for analysis. The results are shown in Table 1.

TABLE 1.—*Analyses of Composite Ore Samples from Diamond Drill Holes*:

Hole Number	23	24	25	85	115	115	144	146
Silica (%)	29.84	27.85	31.44	35.09	31.20	19.55	34.22	27.92
Sulphur (%)	16.23	17.08	10.63	16.08	10.69	20.87	14.87	15.26
Iron (%)	27.90	29.65	24.80	24.95	23.00	35.50	26.60	27.65
Arsenic (%)	0.02	0.039	0.07	0.08	Trace	Trace	0.09	0.03
Copper (%)	1.45	1.27	0.87	1.59	0.98	0.61	0.90	0.74
Nickel (%)	1.45	1.79	1.19	1.55	1.35	2.97	1.72	1.96
Copper-nickel (%)	2.90	3.06	2.06	3.14	2.33	3.58	2.62	2.70
Cobalt (%)	Trace	0.14	0.01	0.01	0.02	0.01	0.01	0.01
Silver (oz. per ton)	0.20	1.00	0.20	0.30	0.15	0.04	0.19	0.20
Gold (oz. per ton)	0.012	0.21	0.014	0.002	0.007	0.004	0.007	0.005
Platinum metals (oz. per ton)	0.004	0.02	0.006	0.004	0.005	0.004	0.003	0.009

Hole Number	193	302	303	304	306	307	308	310
Silica (%)	41.00	35.08	20.37	25.43	26.25	27.03	23.36	29.68
Sulphur (%)	9.55	12.41	21.49	18.98	17.23	18.85	20.40	16.21
Iron (%)	20.25	22.70	35.40	32.10	29.75	31.40	33.95	27.80
Arsenic (%)	0.06	0.08	0.125	0.03	0.06	0.09	0.08	0.21
Copper (%)	0.80	1.56	1.20	1.79	1.31	0.91	0.90	0.88
Nickel (%)	1.14	1.43	2.57	2.22	2.41	2.60	2.75	2.15
Copper-nickel (%)	.194	2.99	3.77	4.01	3.72	3.51	3.65	3.03
Cobalt (%)	Trace	0.02	0.25	0.25	0.02	0.02	0.02	0.03
Silver (oz. per ton)	0.30	0.16	Trace	0.22	0.10	0.20	0.13	0.18
Gold (oz. per ton)	0.003	0.013	0.03	0.008	0.023	0.007	0.003	0.007
Platinum metals (oz. per ton)	0.003	0.007	0.01	0.006	0.013	0.004	0.004	0.007

Analyses by Ledoux & Co., New York.

These analyses are a fairly accurate representation of the average grade of the mixed ore and rock, within the commercial walls of the orebody. In actual mining operations, some of the rock would be sorted from this ore and thus raise the grade.

GENESIS OF THE ORES

The genesis of the Sudbury ores has been a subject of keen debate for a number of years. The data brought to light by this exploration, which has developed one of the large orebodies of the district, lends a new emphasis to some phases of the problem, and it will be of interest to discuss in a general way the facts concerning the deposits and the various conclusions which may be drawn from them.

The apparently conflicting theories of origin are all based upon certain facts. These *facts*, as distinguished from *inferences*, are enumerated below:

1. The ore generally occurs at or near the margin of the main norite mass. Where the ore is not near the main laccolith ('offset deposits'), norite is always found associated with the ore, or in close proximity to it.

2. The ore minerals are later than the rock-forming minerals of the norite.

3. The ores penetrate and replace the footwall rocks to some extent.

4. The rock associated with the ore appears to be more or less brecciated.

5. The walls of the commercial orebody are usually sharply defined, mineralogically.

6. The norite wall is always spotted with sulphides. The footwall is sometimes spotted, and sometimes barren.

7. The mineralogical content of the 'marginal deposits' is singularly uniform with a fairly constant ratio between the amount of pentlandite and pyrrhotite, although with a slightly more variable quantity of chalcopyrite. The content of the 'offset deposits' is not as uniform as that of the marginal deposits.

8. The usual minerals accompanying typical hydrothermal deposits are scarce or lacking, and in many places the norite associated with the ore is unaltered.

9. The norite laccolith has been differentiated into an upper stratum of acid material and a lower stratum of basic material. Within the basic material are minor amounts of acid rocks.

SUMMARY OF VARIOUS HYPOTHESES

On the basis of these facts, a number of hypotheses concerning the genesis of the Sudbury ores have been offered. In general, they fall into two classes: those which postulate a magmatic origin, and those which postulate that the ores are the result of a later introduction by hydrothermal solutions.

The following is a brief outline of the more important theories concerning the origin of the ores:

Magmatic Segregation by Crystallization of Sulphides.— The older school, headed by Barlow,[12] believed that the ores were formed by a process of magmatic separation in which the sulphides were the earliest minerals to crystallize and were concentrated at the edge of the norite. Barlow believed that the concentration took place according to Soret's principle by which a substance crystallizing from a solution or melt is concentrated in the cooler part of the solution. Others place more emphasis on gravity, and believe that the concentration was due to the sinking of the sulphide crystals.

The principal arguments advanced in support of this hypothesis are: (1) the ore always occurs at the margin of norite, (2) the sulphides are natural constituents of the normal norite.

The main objection to this theory is that microscopic investigation shows that the sulphides are not the first minerals to crystallize, but the very latest, and therefore could not become concentrated in this manner.

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[12] A. E. Barlow: Report on the Origin, Geological Relations and Composition of the Nickel Copper Deposits of the Sudbury Mining District, Ontario; *Canada Gelogical Survey, Annual Report* (1904), 14, Part H; also reprint, *Bulletin* 96 (1907).

Gravitational Segregation of Molten Sulphides at the Base of the Magma.—Coleman[13] believes in the gravitational separation of the sulphides, not as crystals, but as a melt. In support of his theory, he cites the following: (1) The ore is universally associated with norite; (2) where fracturing has occurred along the contact the molten norite and ore have penetrated the footwall, forming *offset deposits;* (4) the norite associated with the ore does not show the typical hydrothermal alteration minerals; (5) the distribution of the ore around the contact corresponds roughly with the volume of the norite lying above the ore.

The objection to this theory, as well as to that of Barlow, lies in the fact that there is evidence of considerable solutional activity in the orebodies, since, to a large extent, they are found replacing the footwall rocks. Coleman ascribes this to rearrangement by subsequent solutions; but it seems improbable that there could be such a large amount of rearrangement without the formation of some typical secondary minerals, *i.e., secondary* in a mineralogical sense.

It is true that in some places the ores are localized in a depression in the floor of the norite, or 'bay-out.' In Falconbridge Township, however, the richest and largest portion of the orebody occurs on a 'bay-in' (Fig. 2), a condition that would be improbable if gravity were the sole controlling factor.

Intrusion of Molten Sulphides after the Consolidation of the Norite.—Howe[14] and Bateman[15] support the hypothesis that the separation took place in a deep-seated reservoir and that the ores were introduced as a separate intrusion of molten sulphides. Their evidence lies in the brecciated nature of the contact and the fact that the ore seems to occur as a cement filling the interstices between the fragments.

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[13] A. P. Coleman: The Nickel Industry with Special Reference to the Sudbury Region, Ontario; *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

A. P. Coleman: Magmas and Sulphide Ores; *Economic Geology* (August, 1917), 12, 427–434.

[14] E. Howe: Petrographical Notes on the Sudbury Nickel Deposits; *Economic Geology* (1914), 9, 505-522.

[15] A. M. Bateman: Magmatic Ore Deposits, Sudbury, Ont; *Economic Geology* (August, 1917), 12, 391–426.

As mentioned above, the ore deposits have to some extent the characteristics of deposits from solution and are not clear-cut intrusions of molten material. Moreover, the roughly constant proportions of ore and norite indicate that the segregation must have taken place within the laccolithic chamber now occupied by the norite mass. This relationship will be developed more fully in the course of this paper.

Deposition by Hydrothermal Solutions.—Other observers, as Knight[16] and Dickson,[17] see no immediate relation between the norite and the occurrence of the ore, and observing that the ore occurs mingled with the footwall granite, quartzite or greenstone, as the case may be, as well as with the norite itself, come to the conclusion that the ore is formed by hydrothermal solutions which have permeated the contact zone between the intrusive and the footwall.

The ore is considered to be a cement, replacing the fine-grained matrix 'of 'crush conglomerates' and 'crush breccias.' The improbability of gravitational segregation is suggested by pointing out the dyke-like nature of the norite mass in several localities. The solutions which formed the ore presumably came from depth at a period later than the hardening of the norite to rock, and had no immediate relationship with the adjacent norite, but perhaps were derived from the same source that supplied the norite magma.

Knight cites geological conditions in the vicinity of the Creighton mine to support the theory of ore deposition by hydrothermal solutions coming subsequently to the hardening of the norite and after the intrusion of a supposedly younger granite, thereby inferring that the process of ore deposition did not immediately accompany the intrusion and solidification of the norite. If his inferences have truth, it is not clear why the contact of greenstone (see Fig. 1) and the supposedly younger

[16] C. W. Knight: Origin of the Sudbury Nickel-Copper Deposits; *Engineering and Mining Journal* (May 6, 1916), 101, 811–812. Geological Relations of the Sudbury Nickel Ores; *Engineering and Mining Journal* (Sept. 23, 1916), 102, 554–555. *Report of Royal Ontario Nickel Commission* (1917), 105–211.

[17] C. W. Dickson: The Ore Deposits of Sudbury, Ontario; *Trans. A.I.M.E.* (1904), 34, 3-67.

granite has not somewhere yielded sulphides—for instance, in the vicinity south of the neighboring Gertrude mine. The point of this question is that no sulphides occur along the contact of the granite except where it meets norite. The greenstone might be expected to have lent itself quite as readily to fissuring and replacement as the norite. A traverse of this supposedly younger granite mass indicated to us that it is in reality older than the norite.

The writers have examined considerable portions of the contact between the norite and the granite in the area from the Creighton mine to the Copper Cliff offset, and nowhere see evidence to the effect that granite intrudes norite, except near Clarabelle Lake along the Copper Cliff offset, an occurrence that may well be a local later intrusive. It is possible that some of the supposed granite dikes observed by Knight, along the contact, are of granitic material segregated within the norite mass, similar to that occurring in Garson and Falconbridge Townships, which has been described in this paper.

The granite mass of the area between the Creighton mine and Copper Cliff mine is not a homogeneous body, but contains infolded greenstones and schists. The types of granite vary from coarsely porphyritic to fine-grained; the various phases are intrusive one into the other; and the area bears all the characteristics of an old Archean-Lower Huronian complex. Even assuming that the granite mass is one homogeneous body, the relation of the norite to the granite at Copper Cliff No. 2 mine is a difficult matter to explain. The space relations shown by a detailed areal map of this vicinity indicate that the norite is the intrusive body rather than the granite, since a tongue of norite cuts across the granite.[18]

Wherever the norite contact has been viewed in the Townships of Denison, Graham, and Snider, the textures and mineralogical constituents differ at the immediate contact from the characteristics shown within the mass. These variations are not the result of dynamic changes, but are a strict function of

[18] A. P. Coleman: *Nickel Industry*. Geological Map of Copper Cliff Offset.

the distance from the contact, and point to the fact that the norite has the change in grain at the contact due to differential segregation rather than the granite. This leads to the conclusion that the granite is older. The granite complex has suffered more regional deformation than the norite, as a walk along the Algoma-Eastern Railway, between Crean Hill mine and the Gertrude mine, will make apparent. This points to the older age of the granites. Deductions proceeding from a few obscure contacts cannot be permitted to outweigh the large field relations. It is our opinion that the suggested intrusive relation of the granite into the norite is not proven. This is borne out by other observers.[19] Viewing the subject as a whole, evidence based on the age relationship of this granite mass cannot be considered as having great weight in arriving at a hypothesis which accounts for the origin of the ores.

The hypothesis that pre-existing cavities in the form of contact cooling fissures or brecciation zones were filled by the work of solutions does not seem tenable. It is difficult to account for the presence of extensive brecciated zones, 50 to 150 ft. (15 to 45 m.) thick, on the bottom contact of a mass of solidifying magma 10,000 ft. (3048 m.) thick, with an over-capping of the whole Animikie series having an additional thickness of 10,000 ft. The prevalent inward dips of the norite mass and the relations of the overlying Animikie sediments argue strongly that the present contacts, which are now brought to the surface by erosion, were deeply buried at the time they were formed. Fissured zones of the magnitude necessary to provide for the orebodies could not exist under a capping of miles of rock.

The apparent brecciation and presence of vein-like stringers of sulphides can be accounted for as phenomena accompanying the solidification of both the norite and the sulphides. On the instant that the openings began to form as a result of readjustment which accompanied the solidification of the norite, they were filled with the still molten sulphide. The intrusion and

[19] A. P. Coleman: Geological Relations of the Sudbury Nickel Ores. *Engineering and Mining Journal* (July 8, 1916), 102, 104–105.
E. Howe: *Loc. cit.*, 521.
C. H. Hitchcock: Personal Communication.

solidification of so great a mass of magma is not to be thought of as a simple, brief process; on the contrary, a long time interval was no doubt involved, accompanied with the interplay of enormous pressures. Perhaps the nearest visible analogy to conditions prevailing at the base of the intrusive are those at the edge of a slow-moving glacier, where ice flows under pressure, entraining fragments from the surface over which it moves, melting and congealing, changing continually from solid to liquid and back again to solid; fractures are no sooner produced than healed again.

The fact that nickel-bearing ores are nowhere found at any considerable distance from bodies of norite shows that their introduction into the footwall was essentially a part of an intrusion phenomenon occurring near or within the zone of rock flowage, and that the process was one of penetration by digestion or 'magmatic stoping,' rather than by the replacing of breccias.

Much hydrothermal activity did occur in open-faulted zones, which cut the rocks above the cooling nickel-bearing sill, as the blende and pyrite occurrences in the interior of the basin indicate, but no nickel deposits are found there. It is not necessary to assume the existence of fissures to account for the intrusive nature of the Worthington and Copper Cliff norite masses. It is necessary only to predicate the pre-existence of zones of weakness which, at higher levels in the Animikie rocks, manifested themselves as faults.

The region where the offsets are now found was once covered with nickel-bearing intrusive. The evidence for this is the heavy erosion which must have been necessary to produce the present distribution of the Animikie sediments and norite. Small plasters and remnants of norite are found exposed in many places exterior to the basin proper. The material composing the offsets is norite identical in composition with the norite of the basic margin. The rocky nature of the ores in the offsets and the so-called 'solution boulders' are evidence of more fluidity and circulation during the cooling than in the marginal deposits. This can be accounted for on the basis that the 'offsets' were the deep-seated zones of weakness corresponding with the faults

above and were places of constant readjustment during the long cooling process.

Schistose phases have been developed in the norite, as may be seen in many places along the contact, as in the Townships of Denison, Blezard, and Falconbridge. Large areas of schists are also to be found among the acid phases of the norite in the interior away from the contact. These schists were developed after the rock had hardened from the melt, for the reason that they may be traced directly into normal crystalline norite within short intervals. The schists occur in large volume, measurable in hundreds of cubic yards. The norite which has thus been rendered schistose must have been in a region of great pressure at the time when the schists were developed. There could have been no large openings filled with brecciated norite or footwall in the immediate vicinity, certainly none of sufficient size to account for the orebodies. The ores themselves exhibit the effect of pressure. (See an able paper by Howe.[20]) It is reasonable to suppose that the dynamic changes in the ores and the surrounding rocks occurred at the same time.

A conclusion may be drawn from these facts and inferences: At some time subsequent to the formation of the ores, while the whole mass was yet in the zone where deformation occurs by plastic yielding with the development of micas among the ferromagnesian minerals and incipient fracture in the quartz and feldspars, both the ores and the adjacent rocks were subjected to pressure. All of which argues the previous existence of the ores in this zone before deformation occurred and before the region had been lifted out of that zone, either relatively by erosion or by actual uplift. The deformation now evidenced by the schist and ore may have occurred during the initial stages of that uplift. It might be maintained that the ores had been formed in a brecciated zone and subsequently deeply buried, to permit the phenomenon exhibited, but it is not a reasonable or likely explanation and is not in accord with the usual geological history of the district.

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[20] E. Howe: Petrographical Notes on the Sudbury Nickel Deposits; *Economic Geology* (1914), 9, 505–522.

It is difficult to see how it would be possible to arrive at just conclusions concerning the value of any tract of land on the nickel-bearing intrusive if one proceeded upon the theory that later hydrothermal solutions coming from below attacked the norite and footwall along planes of weakness. It would seem that during the period through which this district has been open for prospecting, someone would have found orebodies along the many shattered zones within the mass of the norite itself, remote from its bottom contact. The regular and uniform occurrences of the ore at the immediate base do not point to the action of vagrant hot solutions. It might be asked, if hot solutions subsequent to the cooling of the norite have in reality been the source of the ore, why orebodies should not have been developed in greenstones and graywackes of the complex distant from the occurrences of norite, as in the silver veins of the Cobalt district, where silver is often found at considerable distances from the diabase with which the mineralizing solutions are thought to have been genetically related.

Magmatic Segregation by Extraction from Crystallizing Norite.—Tolman and Rogers[21] recently proposed a very plausible theory to account for the origin of the ores. They hold that as the process of crystallization of the norite proceeded, the sulphides were extracted by the mineralizers present, and finally deposited, as a last stage in the consolidation of the magma, along the basal contact.

This process is a separation of the ores from the magma practically in place, and in that sense is *magmatic segregation.* On the other hand, the mineralizers present caused replacements in both the footwall rocks and in the cooling norite above, and hence gave the orebodies the appearance of having been deposited from *solution.*

Tolman and Rogers have formulated from detailed microscopic study a succession for the minerals in the norite as follows: (1) silicates, (2) magmatic alteration of pyroxene to hornblende, (3) magnetite, (4) pyrrhotite, (5) pentlandite, (6) chalcopyrite,

[21] C. F. Tolman, Jr., and A. F. Rogers: A Study of the Magmatic Sulphide Ores; *Leland Stanford Junior, University Publications.* University Series (1916).

(7) hydrothermal alteration of silicates to tremolite, chlorite, etc. On the basis of this succession, they have determined the age of the ores to be later than the magmatic hornblende and earlier than any hydrothermal minerals, and, therefore, place it definitely at the close of the magmatic period.

The essential difference between this theory and Coleman's theory is that less stress is laid upon the part played by gravity, and that the segregated sulphides are considered to have more the character of a solution than a melt.

Although we are not willing to accept without qualification all of the conclusions which they draw from the microscopic evidence, yet their theory appeals to us as being the most plausible explanation yet offered to account for the genesis of the Sudbury ores. Especially convincing is the accumulative evidence gathered from world-wide sources that there is a distinct type of sulphide ore deposits the origin of which can be traced to magmatic segregation.

THE RELATION BETWEEN THE EXPLORATION AND THEORIES OF ORIGIN

A choice between the various hypotheses previously discussed is a matter of great importance to the explorer who is endeavouring to conduct a rational search for ore. Such a choice of views is important not only in reference to the value of any one parcel of land along the contact, but also in regard to the handling of any one drill hole. There is one condition common to all of these theories: The orebodies that have now been found do occur along the contact of norite with some other adjacent rock. This is true not only of the sill as a whole, but of the offsets as well; although in many of the offsets, sulphides occur throughout norite dikes. Thus any lands along the norite contact might be expected to carry ore. The explorer must answer this question: Which lands among those along the norite contact warrant the greatest expenditure for the purpose of finding ore? Every consideration that will help in solving this difficult problem is of great importance.

When this exploration was started, the later publications by Tolman and Rogers[22] and by Knight[23] were not available, but a study was made of existing publications.

In the early stages of the work, drilling was carried on, simultaneously, in the various townships indicated on the map, Fig. 1. As far as the immediate local facts in the field might show, all of these localities presented about equal opportunities for finding a body of ore. It may be of interest to record briefly the results of the exploration in the various townships, touching particularly upon the factors which determined the course of the work.

In the Township of Levack, on the north limb of the basin, three holes were drilled between the Strathcona mine and the Levack mine. The relative position of these mines led to the belief that ore might be found along the norite contact between them. Only one hole was drilled to the contact. This hole is typical of many of the holes drilled and is therefore described. It started in a uniform phase of the norite and continued in this for a depth of 500 ft. (152 m.); the proportion of pyroxene and basic minerals increased as the hole deepened, and many anhedra of pyrrhotite appeared. Between the depths of 500 and 600 ft., portions of the core were composed largely of basic minerals; other portions were plagioclase feldspar. These segregations gave to the rock the appearance of having a gneissoid structure.[24] Within this material were found a few occurrences of pyrrhotite and chalcopyrite, each attaining perhaps to as great a volume as 1 cu. in. (16 cu. cm.). At 600 ft. the drill encountered the coarse-

[22] C. F. Tolman, Jr., and A. F. Rogers: *Op. cit.*

[23] C. W. Knight: Geology of Sudbury Area. *Report of the Royal Ontario Nickel Commission* (1917), 105–211.

[24] In the Report of the Royal Ontario Nickel Commission for 1917, Knight describes the Levack mine, and maps this gneissoid segregation as granite gneiss, thus classing it with the basement complex, differing therein from the views of the present writers, who would regard it as a segregated phase of the norite. Similar segregation gneisses are common at the base of the nickel-bearing intrusive elsewhere, as in the Townships of Trill and Denison, and are unquestionably portions of the intrusive. Banding of this type is common in connection with other intrusive bodies. For instance, many such occurrences are found within the Duluth Gabbro, a large sill of Keeweenawan age, in northern Minnesota, according to F. F. Grout of the Minn. State Geological Survey (Personal Communication).

grained, flesh-coloured granite of the footwall, decidedly different from any of the rock above.

Drills working in the Township of Trill in the western part of the district, and in the Townships of Denison and Blezard, encountered much the same types of norite with segregation phenomena near the contact as described in connection with the drill holes in Levack. No commercial quantities of sulphides were found, which, of course, does not necessarily mean that such bodies may not be found. Meanwhile, drills were at work in the Townships of Falconbridge and MacLennan in the eastern part of the district. Typical norite was encountered there also, after penetrating the glacial drift. The norite at the contact in Falconbridge differs in no degree from the norite encountered elsewhere, except that outcrops to the north indicate that the basic portion of the intrusive sill is wider than in the other localities where drilling was done. In attacking this region, it was planned to refrain from deep, costly rock drilling until the position of the contact had been definitely determined by 'scout' holes which would merely penetrate ledge for a few feet. These were put down through the drift for the purpose of marking out the position of the contact; thus the deeper holes had a definite basis for the choosing of their location. In the early stages of the work, one hole near the contact was drilled to a depth of 600 ft. (182 m.) in norite, but did not encounter footwall rocks, thereby indicating that the norite contact had a steep dip.

At this time, lands in the Townships of Bowell, Wisner, and Graham were also available for exploration, but it was decided not to drill them. The drills were withdrawn from Levack, Trill, Denison, and Blezard, and the exploration was concentrated upon the Townships of Falconbridge and MacLennan, where the contact was largely concealed by glacial covering, but where, so far as known, the norite had the same mineralogical characteristics at the immediate base as the norite found during the course of the other explorations. In addition to the drilling, and while it was in progress, studies of many portions of the norite contact were made in the field wherever it was exposed to view.

Volume Relations of Norite and Sulphides

As a result of this work and of a consideration of all the large field relationships as shown on the maps of the Sudbury District, the following general condition had been becoming apparent: The quantity of sulphides which may be expected to occur at the contact of the nickel-bearing intrusive is roughly proportional to the volume of the adjacent norite.[25] The surface expanse of the nickel-bearing intrusive and its thickness as shown by the dip at the contact both go to show what the volume of the tributary nickel-bearing intrusive may be.

The one great expanse of nickel-bearing intrusive in the district which, so far as known, did not have a commensurate body of sulphides accompanying it, lay in the eastern part of the district in the Township of Falconbridge. An inspection of Fig. 1 will show that the nickel-bearing intrusive in this vicinity has a much greater width than in the Townships of Wisner, Bowell, and Levack on the north, or Trill on the west. The norite has a great width in the Townships of Denison and Blezard, but the accompanying orebodies had already been discovered; *i.e.*, Crean Hill mine and Blezard mine. Hence, it was decided to concentrate on the contact in the Township of Falconbridge, even though it was covered by 150 to 200 ft. (45 to 60m.) of gravel and boulders.

In this connection, it may be noted that in regions where the offsets are highly mineralized, the adjacent basic margin does not yield orebodies; *i.e.*, in the region of the Worthington and Mond mines, the marginal contact of the main intrusive is quite generally exposed and no orebodies have been found along it. In the region of the Frood mine, which is found on an offset, the margin proper does not yield orebodies, indicating that the metallic content which was a portion of the magma in these vicinities, when found in one place, does not occur in quantity in another portion of the 'horizontal cross-section' or plan now exposed by the erosion surface. This relationship is, of course,

[25] Coleman, among all the writers on the Sudbury District, has been foremost in recognizing this condition.

rough, discernible only in broad outlines, but is sound evidence for the conduct of exploration, safer than speculation arising from more detailed features of any one hand specimen or any one orebody. General evidence of this kind is more likely to be a safe guide for the projection of work in unknown areas, since the reasoning proceeds from the nature of the intrusive process as a whole, not from any one phase which may be dominated by local conditions.

While the discovery of ore in Falconbridge Township as a result of assuming a relation between the volume of norite and the volume of sulphides may be only a coincidence, nevertheless the outcome is a strong indication that some such close relationship actually does exist.

INTIMATE ASSOCIATION OF NORITE AND SULPHIDES

Another factor which has been emphasized by this exploration is the intimate association of the ore with the norite. In Falconbridge Township, it usually occurs at the immediate contact, the hanging wall being entirely norite and the footwall entirely quartzite (Fig. 4). Where the ore is actually within the quartzite (or greenstone) it is never more than 20 or 25 ft. (6 or 7 m.) from the base of the norite. Moreover, the drill core often shows that the gangue within the ore is norite, while the rock above and below may be quartzite or greenstone.

This is well illustrated in Hole 308, a cross-section of which is shown in Fig. 5. Below the main body of ore, the drill passed through 16½ ft. (5 m.) of barren quartzite only to enter again a 2½ ft. (0.76 m.) stringer of rich ore containing small included particles of *norite*. The association of the norite with this last shoot of ore is extremely suggestive, and points strongly to the fact that they both came from the same source and were closely contemporaneous.

GRANITIC MATERIAL

The constant presence of the granitic material associated with ore at the contact, as described in detail previously, is

indicative of the final breaking up of the melt at the contact into two poles; one the very basic sulphides, and the other the acid phase or granite. The differentiation of the main laccolithic sheet on a broad scale into norite at the base and micropegmatite at the top is a larger manifestation of this segregative tendency.

In view of this tendency of the magma, which appears to be especially noticeable near the contact, it is most natural to conceive that the ores are simply one phase of the differentiation. The present knowledge of the physics or, as it might be termed, the physiology of a molten magma, is too speculative to warrant further analysis into the machinery of this splitting up. It is sufficient to note that the broad field relations force this conclusion—the sulphides and the accompanying rock phenomena developed essentially *in situ*.

UNIFORM CONTENT

The uniform content of the ores and its bearing on their genesis has been previously emphasized by Barlow and Coleman. This feature is illustrated by Figs. 6, 7, 8, and 9, which show a remarkable similarity in content of the samples taken from separate drill holes as previously noted. This relationship holds in a general way for all of the *marginal deposits* in the Sudbury District. It is difficult to believe that solutions coming from any great distance would be capable of producing so many singularly uniform deposits over such a large area. The fact that the *offset deposits* are not of this uniform character and are known to show more resemblance to typical hydrothermal deposits is of special significance in this connection. The regularity in content seems to be a function of the proximity to the main norite mass, and ties up the source of the ores more definitely to the immediate norite laccolith.

SULPHIDES IN WALLS

The character of the walls of the Sudbury orebodies has a distinct bearing upon the question of the origin. The contact of the *commercial orebody* in any one spot is usually sharp and well

defined. There is no mineralogical gradation, as sometimes described, although an actual 'mining gradation' may be found which is due to blocks of included rock near the wall, or to veinlets of ore penetrating the wall. This fact is usually pointed to as evidence of hydrothermal origin. The character of the wall-rock outside of this commercial zone, however, varies, depending on whether it is *norite*, or one of the *basement rocks*.

The norite wall is always spotted with blebs of sulphides. The spotted norite passes, by insensible gradations, into barren norite containing practically no sulphides.

Where the wall-rock is granite, greenstone, or some other rock, it is not always spotted with sulphides, being sometimes entirely free from the presence of ore minerals within a few inches of the ore. Of 35 drill holes which penetrated quartzite contacts in Falconbridge Township, only eight of them showed any noticeable sulphide mineralization in the quartzite, beyond the commercial wall.

During the course of drilling and field study, it has been found that ore occurrences in the footwall are not functions of the character of the footwall rocks, but that masses of sulphides replace quartzite, graywacke, granite, and greenstone, irrespective of their widely different chemical and mineralogical compositions. In the study of ore deposits caused by replacement through the agency of hydrothermal solutions, if any one fact is brought out with emphasis, it is that hydrothermal replacements depend directly upon the character of the rock replaced. There can be no question that replacement of the footwall rocks occurs in connection with every orebody in the district, but there is nothing irrational in assuming that a molten magma and the hydrothermal solutions immediately emanating from it might not be just as efficacious in this regard as the hot solutions coming from any supposed distant magmatic reservoir. The assumption that the immediately adjacent melt was the active replacing agent would give a rational explanation for the widely different rocks which are attacked. That is, the molten sulphides and the accompanying solutions were injected into the positions where they did their work, because they were a part of the solidi-

fying intrusive mass of norite in that immediate vicinity, and not because the nature of the various rocks replaced was essentially favourable to the replacement.

Absence of Typical Hydrothermal Minerals

There has undoubtedly been alteration in the footwall and in blocks of norite enclosed with ore. However, wide field examination fails to show the extensive alteration that usually accompanies large orebodies of exclusively hydrothermal origin as described, for instance, in connection with the Bisbee Copper deposits[26] or the lead-silver deposits of the Tintic district of Utah.[27]

There is no special alteration of the footwall immediately accompanying the ore, but the footwall, in nearly all cases, shows only the original alteration common to any of the older rocks in the district. The mass of the norite itself adjacent to the orebodies gives no evidence of alteration, as distinguished from the norite mass in any other portion of the intrusive body.

The absence of the usual hydrothermal alteration products in the norite suggests that the norite must have had sufficient temperature to be virtually in equilibrium with the solutions carrying the sulphides, permitting replacement without alteration.

Summary

By way of summary, a possible succession of events which produced the Sudbury ores is outlined below:

A laccolithic mass of molten rock was intruded along a plane of unconformity beneath the Animikie sediments. Through some process of differentiation,[28] the nature of which is uncertain, this mass separated and consolidated into two distinct

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[26] Y. S. Bonillas, J. B. Tenney, and Leon Feuchère: Geology of the Warren Mining District *Trans. A.I.M.E.* (1916), 55, 284–355.

[27] Guy W. Crane: Geology of the Ore Deposits of the Tintic Mining District; *Trans. A.I.M.E.* (1916), 54, 342–355.

[28] Bowen would ascribe this differentiation to the sinking of the pyroxene crystals. N. L. Bowen: Later Stages of the Evolution of the Igneous Rocks; *Journal of Geology* (Nov.–Dec., 1915), 23, *Supplement*, 1–91.

but intergrading types, micropegmatite and norite. The sulphides were carried downward with the norite. As the norite consolidated, these sulphides remained in solution and were concentrated in association with an acid component of the magma. This segregation or 'extract' made its way to the base of the norite under the influence of complex chemical and physical forces. At the very last stage in the consolidation of the norite, the sulphides were precipitated from the 'extract' along the contact, and at the same time the acid component solidified into granite, The presence of water, sulphur, and possibly other mineralizers in the magma, gave this extract somewhat the character of a *solution*, enabling it to replace the wall rock to some extent. But it was still so intimately related to the magma that it was unable to carry the sulphides any great distance into the footwall, unless also accompanied by the molten norite.

With this point of view, it is merely a question of emphasis whether these ores are considered to be of magmatic or hydrothermal origin. The point we have tried to make clear is that the dominant factor controlling the deposition of the Sudbury ores is *magmatic segregation in situ*. Hot solutions may have been active, but only served to influence the local character and position of the ores.

DISCUSSION[29]

MR. J. A. DRESSER: A striking feature of this paper is the announcement of the discovery of a new orebody in a drift-covered area by refined methods of exploratory work. The work described by Mr. Roberts is interesting and instructive, and exemplifies the application of the best means yet attained of exploration for new orebodies. Also in the development of prospects once found, there is so often a great loss of capital between the finding of the prospect and its development to a stage to prove whether it is to be a mine or not. The number and cost of ruinous developments that take place from the building of

[29]See also *Bulletin A.I.M.E.*, No. 136, April, 1918, for report of discussion at New York meeting American Institute of Mining Engineers.

plants that are not needed, or are out of proportion to the orebodies, or are in wrong places, is appalling. Doubtless such errors and their consequent losses are gradually being reduced by the introduction of better methods of exploratory work, such as Mr. Roberts has described, but that they still persist to a costly degree none can doubt. From a broader point of view, it may be added that improved exploratory methods both effect economy in the development of new districts and greatly aid in finding extensions and repetitions of bodies already known. That is, such methods make for economy in new camps and tend to prolong the life of older ones.

MR. C. A. O'CONNELL: While I agree with much that has been said, I also would emphasize that mining calls essentially for vision and optimism, without which it would not be the important industry that it is. The development of many of the mines in Northern Ontario furnish many excellent cases in point. Much is due in that country both to the optimistic prospector, and to the venturesome capitalist.

MR. A. R. WHITMAN: I did not understand from Mr. Roberts whether, in his opinion, the ores were deposited from aqueous solutions or by magmatic segregation.

MR. ROBERTS: The presence of the free quartz through the ores is probable evidence that much H_2O in some form was present at the time the ores were deposited, but we believe that the ore-forming process took place during the *later phases* of the solidification of the norite mass during a time when great earth stresses were compressing the slowly cooling magma. In this sense much aqueous activity did occur in connection with the deposition of the ores. But we do *not* believe that the ores were formed by hot waters or 'igneous after-effects' which may be supposed to have permeated fracture planes in the previously solidified norite and in breccia zones of 'country rock.' This postulates a process similar to that which formed the gold ores of the Porcupine District. Anyone who has visited the two camps cannot fail to have observed the marked contrast of the 'aqueous' type of ore deposition as compared with the Sudbury type. All the rocks of the Porcupine District are sericitized,

carbonatized, and serpentinized beyond recognition over large areas, thus giving evidence of alteration by volumes of hot waters — the after-effects of igneous intrusions. These same aqueous agencies were responsible for the deposition of the quartz veins. The effects of this process are very different from the results accompanying the deposition of the Sudbury sulphides, which we believe were controlled dominantly by magmatic segregation *in situ*. The norite accompanying the ore is fresh and unaltered. The greenstones, greywackes, and granites composing the footwalls of the orebodies do not exhibit the marked alteration of the Porcupine greenstones. Thus we cannot assent to the belief that the Sudbury ores were deposited by aqueous agencies in the sense that it was a process similar to the deposition of the Porcupine gold-bearing quartz, but we quite readily agree that much aqueous activity did accompany the intricate process of segregation which produced the large sulphide masses of the Sudbury District.

Mr. C. W. Knight: I congratulate Mr. Roberts and Mr. Longyear on the character of the splendid exploration work done at Sudbury. These geologists spent a little less than a quarter of a million dollars on their exploratory work, and the money was spent entirely under their direction. The expenditure of this large sum by two geologists shows the growing confidence which mining concerns are now placing in geologists of the type of Messrs. Roberts and Longyear.

Regarding the origin of the ores, these workers consider that the sulphides were precipitated from an 'extract,' and that the 'extract' had somewhat the character of a 'solution,' on account of the presence of water, sulphur, and other mineralizers. The authors remark that "it is merely a question of emphasis whether these ores are considered to be of magmatic or hydrothermal origin."

I agree with the authors that the ores may have been precipitated from hydrothermal solutions. That is the theory which most geologists have now accepted in so far as the Worthington mine is concerned. How these magmatic, ore-bearing solutions were concentrated from the cooling magma towards the

basic edges of the norite is a subject regarding which there will be discussions for years to come. That magmatic waters played a prominent part in the formation of the ores is very well shown at the Garson mine, where 35,000 tons of quartz have been actually mined and shipped to the Mond smelter.

The authors also agree that the sulphides were deposited after the rock-forming minerals of the norite had solidified. This conclusion is in agreement with the recent trend of opinion regarding the relation between the ore and norite.

The work of Roberts and Longyear also confirms the statement that the norite does not always occur in the form of a sill. They have shown, for instance, that at the Longyear deposit the norite contact for a distance of three miles is vertical. Immediately west of their deposit, at the Garson and Kirkwood, it is known that the contact is more or less vertical. Including, then, that part of the contact along the Kirkwood, Garson, and Longyear deposits, it is now positively proved that for six continuous miles the norite contact is more or less vertical, proving that here the norite is dyke-like, not sill-like.

It is to be hoped that the class of work accomplished by Messrs. Roberts and Longyear will be repeated in Canada. That is the kind of practical, geological exploration which is welcomed.

MR. L. C. GRATON: Whether one may accept or oppose the geological arguments and conclusions expressed in this paper, he must feel that in one respect, at least, the geologists who are its authors have afforded us a fine example of what a geological paper ought to be, in that not until after they had found the ore did they attempt to talk about hypotheses or origins or localizations.

The prime object of the geologist as a scientist is to find the truth. The prime object of the geologist as a practitioner is to find ore. The scientist will surely find more of the truth and find it more quickly if he has had experience in applying his theoretical ideas to the practical business and exacting test of ore-finding. And on the other hand, the professional mining

geologist cannot hope to be really successful (as contrasted with lucky) unless he possesses an acquaintance with and respect for the scientific principles of ore deposition as thus far ascertained and understood. When, as in the present instance, two young men, after having investigated and appraised the scientific aspects of the problem, deduce and decide upon a systematic and definite programme of exploration, which they back not only with their company's money, but with their own reputations as well, and when in direct consequence of the prosecution of such a programme they disclose an orebody of the probable magnitude indicated, it looks to me like a pretty good case of combining theory and practice, science and application. It may be that the premises on which they proceeded were partly or wholly wrong; I may confess, indeed, that I am not in complete sympathy with some of them; but up to date we possess no more impressive or convincing test of a geological hypothesis than this one of actually applying it to a piece of ground and actually finding the predicted or expected conditions—what Van Hise has called "geology made to order."

Under these circumstances, particularly, it seems to me that the degree of fairness with which the authors have briefly reviewed in this paper the various ideas of origin that have been proposed for the Sudbury ores and the modesty and moderation with which they express their own preference for a particular one of these views, reflects, equally with the outcome of their activities in the field, a great deal of credit upon them.

DR. A. P. COLEMAN (*communication to the Secretary*): The paper by Roberts and Longyear on the "Genesis of the Sudbury Nickel-Copper Ores as Indicated by Recent Explorations" is one of the most interesting and important recent contributions to the rapidly growing literature on magmatic segregation of sulphide ores. It presents the results of a large amount of careful field work covering new ground in the nickel region, and the theoretical conclusions are stated with much caution.

Their work has put the theory of magmatic segregation to the severe test of exploring beneath a great thickness of drift and

actually finding one of the largest known orebodies about where it should be according to the geological map of the region as interpreted by the magmatic theory. It may be permitted the present writer to recall the following somewhat prophetic phrase: "It may be that exploration through the Pleistocene beds along this supposedly barren stretch will, in the future, disclose valuable orebodies."[30]

The concluding sentences of their paper, "that the dominant factor controlling the deposition of the Sudbury ores is *magmatic segregation in situ*. Hot solutions may have been active, but only served to influence the local character and position of the ores," agree with the views expressed by the present writer and held by most of the geologists who have actually worked in the region.

On two or three points, however, the authors of the paper hesitate to express their agreement with the usual theory of segregation aided by gravity, though the facts which they publish seem to support it strongly.

They say that "this segregation or 'extract' made its way to the base of the norite under the influence of complex chemical and physical forces," but give no idea what these forces were. Their account shows that the portion of the magma containing the sulphides remained fluid after the ordinary rock-forming minerals had crystallized. This 'extract' must have consisted mainly of sulphides with a specific gravity nearly double that of the rock minerals. It seems clear that the physical force which brought the sulphides always to the bottom of the norite was, above all, gravity. It is interesting to find two independent workers, Goodchild in the Insizwa Range of South Africa,[31] and Baker in the Alexo deposit,[32] holding without hesitation that the nickel-bearing sulphides of those regions reached their positions at the base of the eruptive mass by the pull of gravity.

Their doubt as to the part played by magmatic waters, also, seems hardly called for. The water contained in a magma is

[30] Nickel Industry, p. 83.
[31] Econ. Geol. of the Insizwa Range, *Inst. Min. & Met.*, 1916.
[32] *26th An. Rep. Bur. Mines, Ont.*, p. 269.

certainly a part of the general melt, and only when, as the last portion of the magma to solidify, it leaves the rock-forming minerals and begins its subterranean wanderings can one speak of its work as hydrothermal. That water was present either as the compound H_2O or as its dissociated elements in the magma no one disputes, but there is no evidence to show that it acted independently in depositing the main bulk of the ore in marginal mines, since rock-forming minerals are always present in more or less amounts. The sulphides enclosed on a large scale in the pyrrhotite-norite or lying at the margin of the norite from which they have separated in the act of cooling are no more hydrothermal deposits than the quartzes of granites crowded with liquid inclusions are of aqueous origin. If these sulphides are not of magmatic origin none of the later minerals solidifying from a magma have a right to be so called.

The hesitations mentioned, however, are minor matters and do not affect the value of the paper as a whole. It is an admirable presentation of a series of fresh observations bringing new and welcome light on a difficult subject, and the summing up of the theoretical results has been given in a thoroughly impartial manner.

PROF. M. B. BAKER: This discussion of the excellent paper on the "Genesis of the Sudbury Nickel Ores," read by Mr. Roberts, has brought forth a written discussion by Dr. Coleman. In that discussion my name is mentioned in connection with investigations carried on at the Alexo nickel mine in the Porcupine district. I may be pardoned, therefore, for adding some remarks on the Alexo property in this discussion, for Dr. Coleman has claimed that the origin of the Alexo is identical with that at Sudbury.

Some of the points raised by Mr. Graton, in his discussion of this paper, as well as some which were written by Dr. Uglow, would seem to disagree with Dr. Coleman, as to the method and origin of the Alexo ore. Having studied this deposit in detail, I would state that I think both Dr. Coleman and Dr. Uglow are right in so far as they are dealing with certain phases only of the orebody, but I think that neither theory is the complete solution of the difficulty, at either the Alexo or at Sudbury.

The oldest formation in the area is a very compact, hard pillow-lava, of dense texture and of a greenish grey colour when freshly broken; it sometimes has the composition of rhyolite, but more often of andesite. There seems little doubt that it is characteristic Keewatin pillow-lava, so abundant in Northern Ontario. This pillow-lava is so much harder than any rock of the area, that it always stands up as a prominent feature of the landscape, and thus forms the high hill at the Alexo mine, at the northwestern base of which the ore occurs. In contact with this pillow lava is a large mass of peridotite now altered to serpentine. The softer peridotite forms the low, flat, more or less swampy ground about the higher andesite hills.

The orebody at the Alexo mine is at the contact of the peridotite with the earlier pillow-lava. The ore is one of two distinct types. The first is disseminated throughout the peridotite. The second is pure or massive sulphide which occupies spaces, cracks, or other openings along the actual contact, or finer fractures in either wall. The contact of the two rocks strikes northeast and southwest, and has a dip of 65 to 80 degrees to the northwest. The deposit has a proven length of 700 feet, and has been opened up to a depth of 120 feet, and diamond drilling has shown ore at a depth of 240 feet. The width of the orebody, counting both the massive and disseminated ore, is variable. On the 120-ft. level, for example, it is 40 feet wide, while at places on the 75-ft. level it not more than 3 feet. It will average, on all the work done so far, probably 10 feet.

The massive ore consists almost entirely of pyrrhotite, with small amounts of pyrite, chalcopyrite, and pentlandite in mere filaments through the mass. The pieces of ore show it in very fine veinlets threading their way through the massive sulphides. Chalcopyrite is not at all abundant, and occupies small fractures, as if introduced after the pyrrhotite. The smelter returns show less than 1% of copper This massive ore rests directly on the footwall of andesite.

The hanging-wall of the massive ore is disseminated ore, wherever the normal structure has not been disturbed by faulting. The contact between massive ore and disseminated is just as

clean and sharp as is that between massive ore and andesite. Small stringers of massive ore also penetrate the disseminated, and fragments of the latter are sometimes enclosed in the massive; all of which goes to show that there were two distinct periods of ore deposition, and that the massive ore was the later of the two.

Since this property was described by A. P. Coleman and W. L. Uglow much work has been done underground, permitting a closer examination of the orebody than was possible at that time. They claimed that the massive ore, the disseminated ore, and the serpentine rock blend into one another. This is certainly not the case, for a sharp contact exists, which is actually slickensided, between the massive ore and the disseminated. The disseminated ore is always scattered throughout the rock, forming part of its texture and structure, and grades off into barren serpentine; it is only mined as far as it is economical to do so, there being no wall in the ordinary conception of that term. Beyond this transitional phase of the ore, the serpentine is absolutely barren of sulphides even when viewed microscopically.

Coleman and Uglow differ in their opinion as to the origin of the orebody. Coleman compares it to the deposits of nickel-copper ore at Sudbury, and claims that the massive and disseminated ore are due to magmatic segregation, whereby the sulphides settled out as would matte from slag, and therefore occupy the base or margin of the peridotite body, and gradually pass up into it.

Uglow, on the other hand, claimed that the Alexo orebody is the result of metasomatic replacement of the serpentine rock by sulphide solutions, which worked inward from the contact, replacing partly to completely the serpentine rock.

A study of the orebody, microscopic examination of polished ore specimens and of thin sections by the writer, cause him to differ from both of these theories. While it is impossible to enter into a full discussion of this subject here, the following points will summarize the results of the writer's observations:

1. It has been already shown that the massive ore is distinctly later in age than the disseminated, and is, therefore, not a magmatic segregation of the main intrusive mass.

2. The disseminated ore preserves perfectly the rock texture and structure of the peridotite mass.

3. Even the richest of the disseminated ore shows the original olivine crystals intergrown with and surrounded by pyrrhotite, but in no case replaced by the latter. The intergrowth is as sharp and clear cut as is that between quartz and feldspar in graphic granite.

4. Even in the leanest ore there is no sign of attack of any replaceable mineral. The few grains of sulphides visible are in sharp, angular, clean-cut contact with the idiomorphic olivine crystals.

5. In no single case was absorption of the olivine crystals visible, although it is clear that the olivine crystallized before the sulphides.

6. Apparently barren peridotite, away from the orebody, shows by analysis 0.59% of nickel oxide.

It seems clear, therefore, that the 'disseminated' ore was formed as an original constituent of the peridotite, that it settled to the base of the magma by its greater specific gravity, but remained liquid through its lower fusion point. Finally it solidified about and around the olivine crystals which had already formed, and had settled down into the liquid sulphides. This accounts for the disseminated ore, and agrees with Dr. Coleman's theory of magmatic segregation.

After the whole mass had solidified, it continued to cool, and therefore to shrink, and a channel was opened along the contact to deeper portions of the mass, where solidification had not yet taken place. This allowed further sulphides to well up and fill all openings and fissures, thereby forming the massive ore as now found.

MINING METHODS AT THE WORTHINGTON MINE:

With Notes on Underground Contract System

By R. N. Palmer

(Annual Meeting, March, 1918)

The Worthington mine is situated on the Soo branch of the Canadian Pacific Railway, twenty-five miles southwest of the town of Sudbury, the centre of the nickel-mining industry of Ontario. This mine is three miles away from the outcrop of the great Sudbury norite intrusive, in one of the 'offset dikes of norite,' which have been described in geological reports of Sudbury district.

The particular dike in which the mine occurs, and which is called the 'Worthington Offset,' is about four miles long and from 100 to 200 feet wide. It strikes nearly northeast and southwest, extending three miles northeast and one mile southwest of Worthington. The dike cuts through slate, quartzite, conglomerate, and greywacke of the Temiskaming series near the mine, and greenstone one-half mile away to the northeast. The dip of the dike, near the mine, is from seventy degrees to eighty degrees to the southeast. Its filling comprises, as well as norite, a large number of inclusions of greenstone and a rock made up largely of actinolite. Knight believes these inclusions to have come from the earlier rocks cut through during the norite intrusion. These inclusions vary in size from small pieces to large masses, amounting to hundreds of tons weight. In different sections the dike is slightly mineralized with chalcopyrite and pyrrhotite, containing many crystals of pentlandite. The most extensive mineralization has occurred at the Worthington mine, where a body of commercial ore has been opened and nearly 1,200,000 tons of ore have been developed, of which slightly over 1,000,000 tons were above the 600-ft. level.

The sulphide in this orebody does not occur like the massive sulphide in other mines of the district. It is not in one con-

tinuous or mostly continuous body, as in the Creighton and the Levac mines; nor in a series of bodies big enough to develop into large separate stopes, as in the Garson and parts of the Crean Hill mines. At the Worthington some of the sulphide is found in continuous masses, but they are small comparatively, and widely separated by rock, or rock containing stringers of sulphide. The largest bodies of sulphide, always very erratic in position and irregular in shape, are seldom more than 20 feet in diameter. Most of the sulphide occurs, either in still smaller, irregularly shaped bodies between masses of rock, or in a network of veins and coarse stringers surrounding the rock.

The rock masses in the commercial orebody, which probably (as Knight believes) were formed by the crushing and brecciation of the dike before mineralization took place, are found in all sizes, from small grains up to 'horses' extending across the whole ore zone. They are both angular and rounded in shape, the norite being more commonly angular, the greenstone and actinolite rock more commonly rounded. The rock masses, as a rule, contain very little disseminated sulphide, excepting near their outside surface. In the commercial orebody the percentage of rock is considerably greater than the percentage of sulphide; in fact, in many parts of the mine the rock is 85%, and the sulphide 15%, of the total volume.

The pure sulphide in this orebody contains a larger percentage of metal than the average Sudbury sulphide. This is because the percentage of barren pyrrhotite in it is not excessive, there being a considerable percentage of chalcopyrite, carrying 34.5% Cu, mixed with it, and many dark crystals of pentlandite, carrying 22% Ni, studded through both the pyrrhotite and chalcopyrite. Though the pure sulphide is rich, the ore hoisted, because of the rock broken in mining, is the lowest-grade ore at present mined in the district. As a result of the presence of the rich sulphide, however, it is possible, after crushing and sorting out rock, to recover a high-grade ore suitable for direct smelting.

The erratic occurrence of sulphide in the commercial orebody has an important effect on the mining problem. To

properly recover the mineral in mining, it has been found best, where the resulting ore is above the commercial limit, to break down both sulphide and rock together in a continuous stope, relying upon proper rock-house work to discard enough rock and pick out low-grade milling-ore to produce a high-grade ore for the blast furnace. Continuous mining of sulphide and rock is carried on for a length of 800 ft. along the centre of the dike, and to a width of 20 to 60 ft. These dimensions may be taken

Surface Plant at the Worthington Mine.

as the horizontal extent of the commercial orebody. The mine is now working at 750 ft. depth, and gives no indications of discontinuing to a much greater depth.

The large proportion of rock in the orebody might seem to indicate the advisability of following a selective method of mining. The great objection to such a method is the probability of leaving a large percentage of sulphide in the mine behind masses of rock. Such a method of mining was tried here from 1890–1894 when the property was owned by the Dominion

Mineral Company, which also operated the Blezard mine. The uncertainties of the method, especially the difficulties of finding enough sulphide for the miners to work on steadily in order to keep the plant running, made the method unsuccessful at that time. After working a few small stopes near the surface the company closed down the mine in 1894.

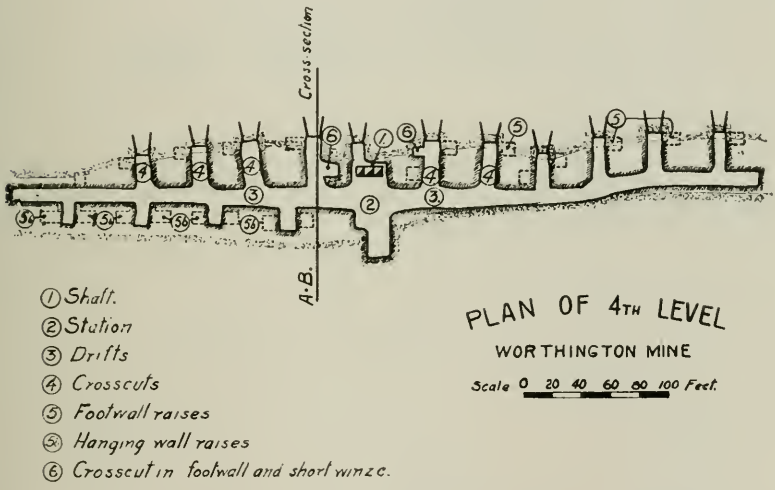
After an idleness of nineteen years the Worthington mine was purchased by the Mond Nickel Company, and new development was started on it in May 1913. The essential parts of a new 600-ton plant were installed by the end of April 1914 when hoisting began. Since that time the mine has produced from 150,000 to 180,000 tons of mine-run ore yearly.

As now worked the orebody is attacked through an inclined shaft sunk close to the footwall. This shaft is timbered with sets placed 6 ft. between centres; these sets comprise 10″ x 10″ footwall plates, 8″ x 10″ hanging-wall plates, and end pieces, dividers, and 8″ x 8″ studdles. The shaft is 7′ x 18′ outside of timbers, has two skip compartments and a ladder-way, respectively 5′ 8″ x 5′ 6″ and 4′ x 5′ 6″ in the clear. The 45-lb. rails used for skip track are bolted to the footwall plates; 4″ x 8″ guides are provided for the safety catches of the combined skip and cage. These guides serve also as back stringers.

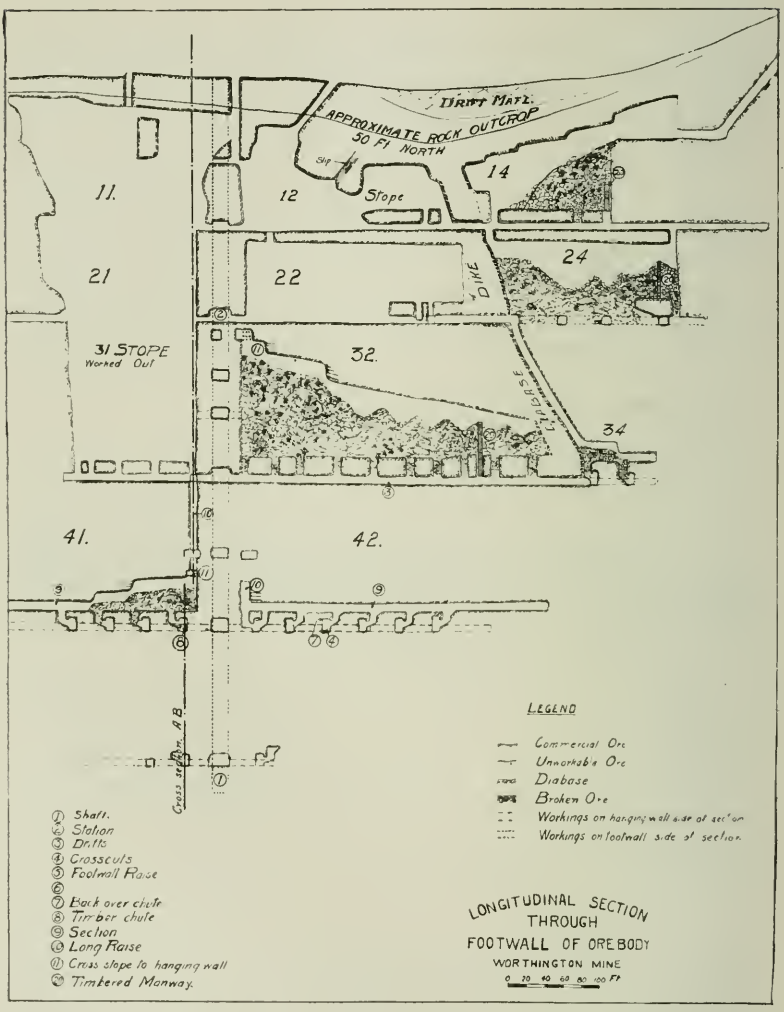
Except for improvements in details, which have been introduced as they have been thought out, the method of mining at present followed (which is illustrated by accompanying sections) has been used throughout since the commercial limit of minable ore has been established and the mine brought up to the tonnage required. But while the mine was in its earlier development stages, it was necessary, in order to establish a commercial mining limit and to start production as quickly as possible, to follow a method which would allow the ore to be hoisted and sorted as broken. Accordingly, most of the first level was mined by underhand stoping. At present, as shown by accompanying sections, levels are being opened up 150 ft. apart vertically, shrinkage stopes are started about 20 ft. above each level and are carried through the floor pillars of the level above. These sections also show that short sub-levels are driven half-way

between haulage levels. These sub-levels extend only to the footwall raise (10) at the ends of the stopes that are nearest the shaft; they provide easy access from the shaft to the large stopes near it, while these are being mined out.

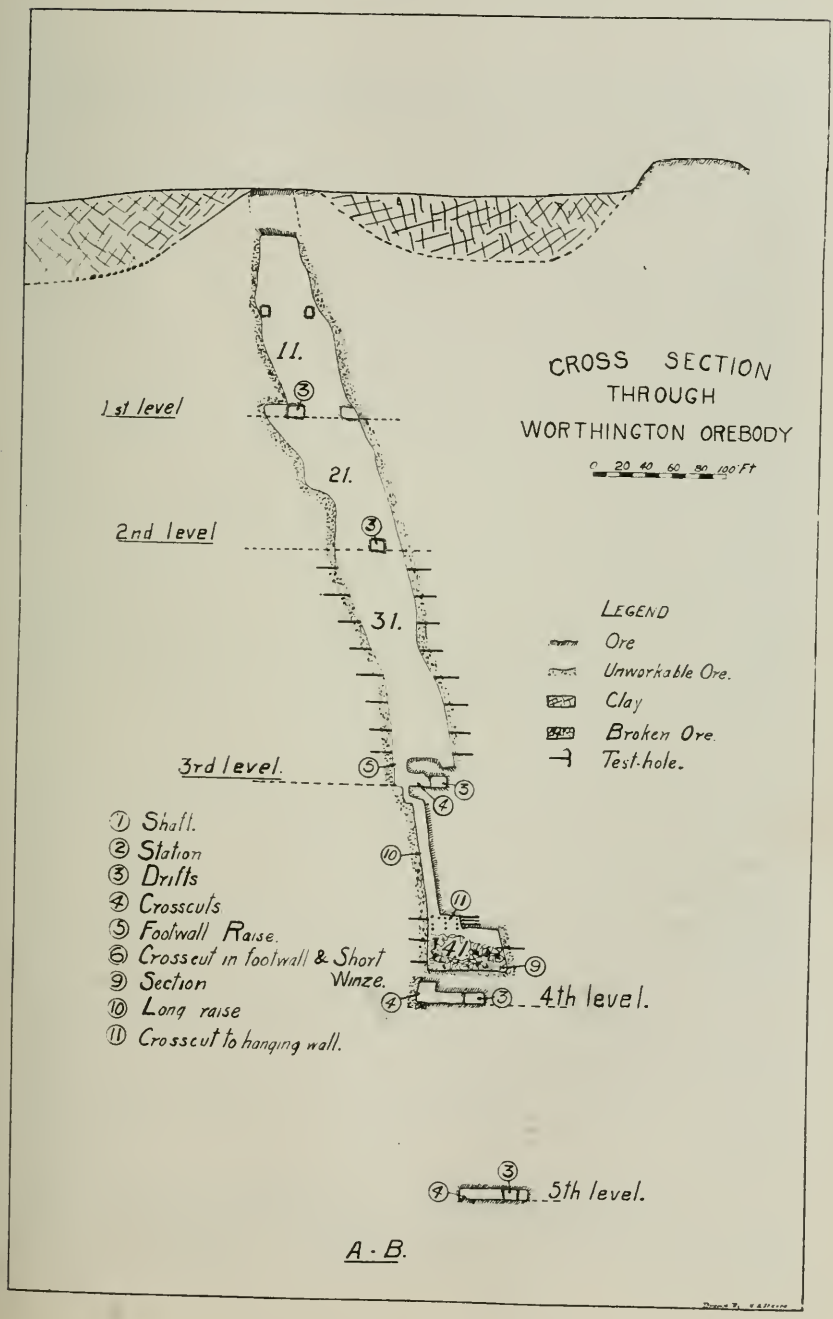
In opening up a level, a station (2) is cut on the hanging-wall side of the shaft and a main crosscut driven through the orebody to the hanging-wall. Drifts (3) are carried both ways from the main crosscut longitudinally through the ore. Crosscuts (4), 40 ft. apart, are driven towards the footwall, and are carried one or two rounds beyond the commercial limits of ore. These, together with the test holes drilled 10 ft. beyond



the face of the last round, thoroughly test the footwall at the level for possible extensions of valuable stringers of ore into the footwall. Where the orebody is wide, crosscuts are also driven towards the hanging-wall to make provision for chutes under the whole width of the ore. Footwall raises (5), to draw the ore into chutes from the stopes above, are started from one side of the footwall crosscuts, close to their end, and well back into the non-commercial footwall. These raises are kept back in this way to make them pull from the footwall,



and to draw the broken ore evenly across the inclined stope as far up as possible. They are driven to a height of 20 ft. above the level, where a section (9) is cut over the full width of the orebody. Section cutting is done by first driving a wide heading lengthwise of the stope, and then slicing off on each side until


CROSS SECTION
THROUGH
WORTHINGTON OREBODY
0 20 40 60 80 100 Ft
11.
21.
31.
41.
1st level
2nd level
3rd level.
4th level.
5th level.
LEGEND
Ore
Unworkable Ore.
Clay
Broken Ore.
Test-hole.
① Shaft.
② Station
③ Drifts
④ Crosscuts
⑤ Footwall Raise.
⑥ Crosscut in footwall & Short Winze.
⑨ Section
⑩ Long raise
⑪ Crosscut to hanging wall.
A · B.

the commercial limit of ore is reached on foot and hanging-walls. When section-cutting has been carried far enough ahead to show the position of the footwall limit of ore, a long footwall raise (10) is made through to the level above, connecting with the sub-level in passing. When stoping is in progress this raise is made use of in starting each new slice, as indicated at (11). A narrow cross-stope 8 ft. wide and 10 ft. high is first driven across the orebody to the hanging-wall. In starting this stope machines are rigged up on crossbars at the lower end of the raise, and flat holes are drilled to break downward. As this narrow stope is carried towards the hanging-wall, horizontal holes are put in at right angles to it, to break the first round in the slice that will next be carried lengthwise of the stope. Formerly, when piston machines were in use, stoping was done by the rill method as indicated in 32 stope, the back being kept just inclined enough to allow all the drilling to be done with water-holes. At present, where water Leyners are used, the slicing is done horizontally, or nearly so. While stoping is in progress a cribbed manway (20) is carried up through the broken material near the lower end of each stope. Besides serving as a manway this completes the circuit of ventilation through the stope.

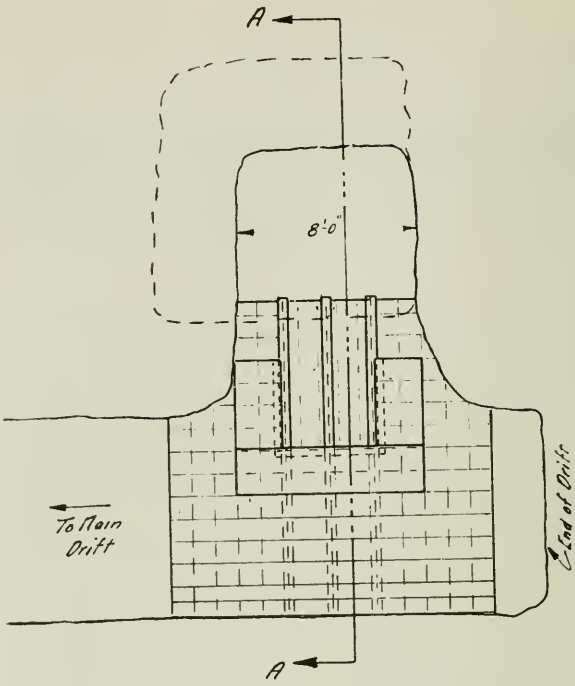
In stoping, the important problem, at all times, has been to decide the commercial limit. This cannot be decided, round by round, as stope slices are carried ahead. On account of the irregular distribution of sulphide, this depends more on the surrounding faces which have been broken, and are to be broken, than upon the one face immediately ahead at any time. The latter may show non-commercial ore, but still need breaking to keep the stope wide enough to get at commercial ore expected from lower slices to lie just ahead. As a result of commercial limit being decided by broad areas, rather than by individual rounds, any widening or narrowing of stopes is made gradually, and the finished stope appears more or less regular.

To assist in deciding the commercial limit to mine to, test holes are drilled 10 ft. deep into the foot and hanging walls of the stopes, and the cuttings are examined. These cuttings are

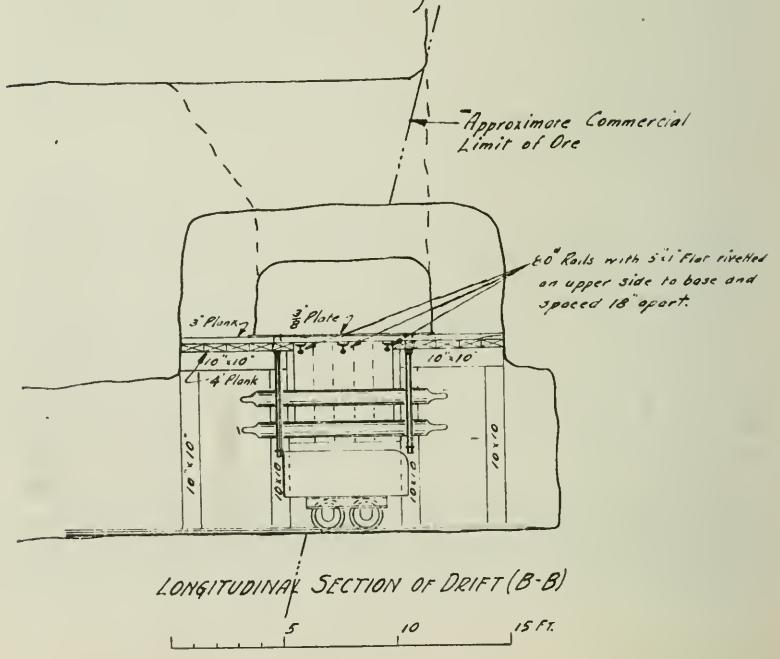
also collected in 2-ft. samples and analysed for metal content. Cross-sections of stopes are kept plotted up-to-date, and test holes are indicated thereon with metal content plotted graphically. These data are considered, along with the physical indications visible in the stopes, in determining the commercial limits of the orebody.

In driving stope slices, holes are drilled from 8 to 10 ft. deep, from 1½ to 2 ft. apart vertically, 6 ft. apart horizontally in the middle of the stope, and 3 ft. apart horizontally for two rows along each wall. Blasting is done with 1¼", 40% forcite gelatine, 8 to 9 sticks being used per hole. Drilling is done with water Leyner type mounted hammer drills, equipped with tappets and chucks to fit 1⅛" hollow, hexagonal steel. 14°–5° taper cross-bits are used, with starters of 2⅛" gauge, and with a change of $\frac{3}{32}$" for every 18" length of run. One man drills from 40 to 70 ft. per shift, depending upon the percentages of sulphide and rock, and the nature of the rock. The least drilling is done along the foot and hanging-walls, especially along the hanging-wall, where the rock is very hard. Tonnage broken per machine per month varies from 2,000 to 3,000 tons, depending upon where work is done in the stope—whether there is considerable mining in the narrow ends of the stope or whether most of it is done in the central and wider parts. Work per man on water drills is double that formerly done on piston machines.

The chutes along the foot-wall, through which is drawn a large percentage of the ore from the high inclined stopes, are made with grizzly rails placed across them to catch all large rock where it can be block-holed before it gets through the chutes into the cars. Where one of these foot-wall chutes is to be made the back of the crosscut is first stoped 14 ft. high for 12 ft. long—that is, for 6 ft. each way from the centre line of the chute. A low drift is carried in for two rounds made at right angles to the crosscut, with the bottom 8 ft. and the back 12 ft. above the level. An 8′ x 8′ vertical raise, with its near side 7 ft. from the centre of the crosscut, is then driven through to the section level, and funnelled at its top. The chutes are made with their sides cut off level 8 ft. above the track. A high sollar, 8 ft. clear

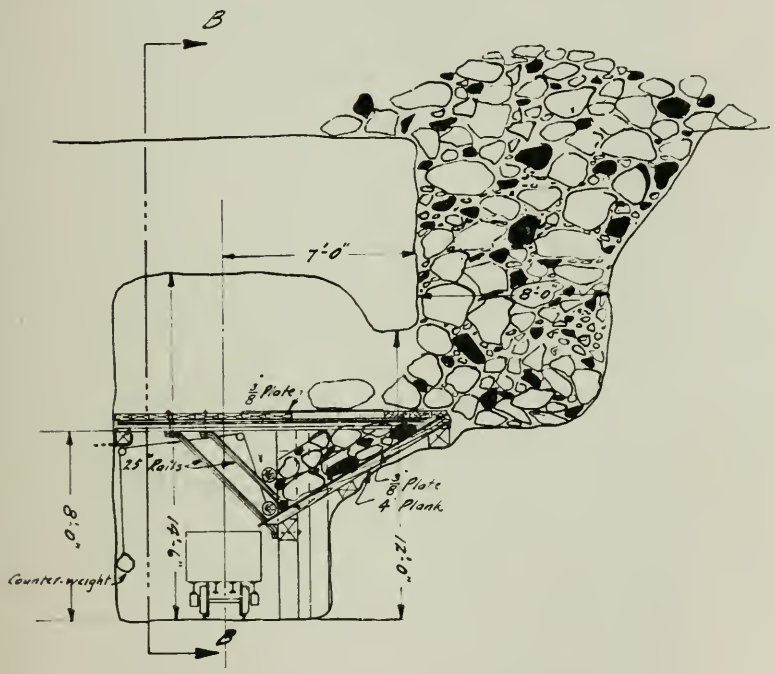


PLAN OF SOLLAR, CHUTE & GRIZZLY



LONGITUDINAL SECTION OF DRIFT (B-B)

above the track, is built on the two sides and in front of the chute for the block-holer to work on when large rock lodges on the grizzly rails. The grizzly rails, and the sollar of 4-in. plank outside of the rails, rest on the ground back of the chute, and, extending across the crosscut, rest on a timber clamped into the rock in front of the chute. The plank sollar outside the



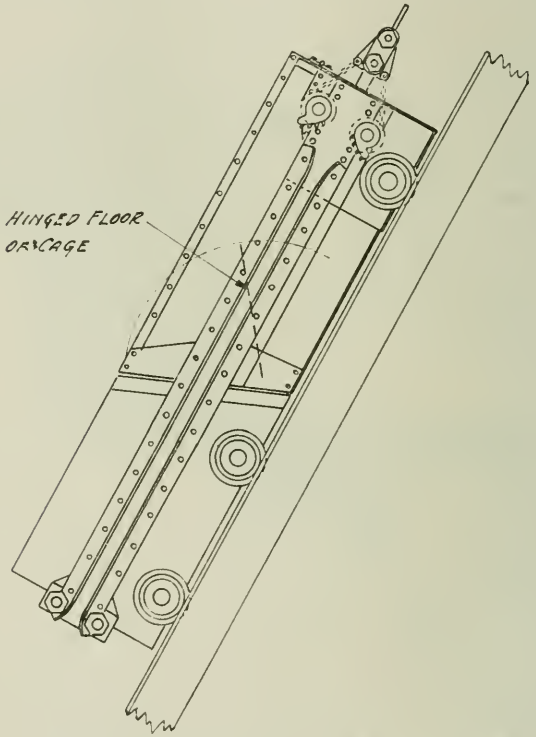
CROSS-SECTION (A-A) OF DRIFT THROUGH CHUTE

5 10 15 Ft.

rails is further supported, outward from the chute posts to posts near the end of the sollar, by two short caps of timber. The space in front of the chute between the rails is filled tightly to protect the trammers when drawing the chute. The sollars in front of the chute and on each side thereof are plated to protect them and to make a good shovelling surface. When these

chutes are in operation fine material is drawn from the raise directly through the chute while the large lumps remain on the grizzly rails, where they are drilled and blasted.

Hanging-wall chutes, which handle only medium tonnage, are made cheaper. Lately a high sollar, inclined at 10° towards the car, with edge just over the car, has been used. The slope



Sketch of Combined Skip and Cage, Worthington Mine.

makes it easy to load from these sollars. Two trammers are able to load and tram up to 50 cars, holding 2 tons each, per shift, from these inclined sollars.

All drifts and crosscuts through the ore are carried 7′ x 9′. Tracks are made of 25-lb. rails on 18″ gauge. Tramming is done by hand in 2-ton cars dumping directly into the skips, two cars making a skipload. As the hoisting equipment has

not been used to capacity while hoisting from the upper levels, skiploading pockets have not been required. As the mine gets deeper they will be needed to save hoisting time.

Each 4-ton skip has combined with it a man-cage directly above it, the whole combination running on three pairs of wheels. This combination is similar, except for the wheels and the shape

Combined Skip and Man-Cage.

it has to take in an inclined shaft, to the combined cage and Kimberly skip often used in vertical shafts. This combination has seldom, if ever before, been used in inclined shafts. It is giving good satisfaction in a mine of this size and makes a separate cage compartment unnecessary.

The rock-house is so arranged that the skips dump the ore directly over the grizzlies, which are made of rails 15 ft. long, spaced 4 in. apart. The oversize collects against heavy, vertical doors, set at right angles to the grizzlies, and 2 ft. beyond their lower end. These doors are 5 ft. 6 in. square. They slide in guides and are lifted vertically by 8-in. air lifts. They permit the oversize to run in proper quantities onto flat, tilting doors in front of them, where preliminary sorting into ore and rock

Sorting large pieces of rock from mine-run material on tilting doors at foot of grizzlies.

is made. Each tilting door is 6 ft. 6 in. long and 3 ft. wide, and is hinged at one end so that the opposite end may be lowered to discharge its load of ore. The free end of the door is hung on an 8-in. air lift, which is used to lower and lift it. When in horizontal position the free end of the door sits on a chair, making it safe to work on. On these tilting doors all the preliminary sorting is done. Any large pieces which are rock, or mostly rock, are sorted out and rolled once over into a rock

chute leading to a large storage bin (2). The ore remaining on the tilting door is slid into a similar bin for ore (1) by lowering the free end of the door. This arrangement makes it possible for two men on each shift to separate out all the large pieces of rock, one man picking out up to 40 tons of rock per shift at times.

Rock feeding into preliminary crusher from storage bin under tilting doors.

This rock and ore is drawn from the storage bins through 5 ft. 6 in. square openings controlled by heavy, vertically lifting doors hung on 8-in. air lifts; it slides directly into jaw crushers which have 18 in. x 24 in. openings; one is for rock and one for ore, set at 4-in. opening. These crushers are made by Hadfields

of 'New Era' steel, which withstands exceedingly well the large percentage of hard norite in the ore.

The ore from bin (1) after preliminary crushing, goes to a bumping table where fines passing $\frac{5}{8}''$ mesh are first screened out and dropped into a bin above railway cars. The coarser pieces of rock and the second-grade milling ore are picked out; the high-grade ore, remaining on the table, passes down over its end into storage bins above the railway cars. The bumping table on which this sorting is done is made in three sections, each 10 ft. long. It is 4 ft. wide and has a channel down its middle 14 inches wide, that receives the rock sorted from the ore and guides it towards the lower end of the table, where it is discharged onto a conveying belt, crossing the rock-house at right angles to the table. The rock from bin (2), after preliminary crushing, goes to a bumping table parallel to the ore table. Here the minus $\frac{5}{8}$ fines are screened out for milling ore, and any larger liberated pieces of smelting and milling ore are picked out. The rock remaining on the table goes to the lower end, where it is discharged onto the cross-belt. The mine-run ore which passes through the grizzly is sorted on a table similar to the first, similar products being made.

On account of this third table receiving much rock between $\frac{5}{8}$ in. and 2 in. mesh, which is difficult to hand-pick, experiments are being carried on at present with a view to jigging this size of material in Woodbury jigs.

The rock passing over the end of the three picking tables is conveyed by the cross-belt of a third Hadfield breaker, set to crush $1\frac{1}{2}$ in. The fine rock resulting from this crushing is taken away by the C.P.R. for ballast.

The necessary rock-house plant is now being installed to recover more metal from the rock waste. The recovery made must be of high enough grade to stand freight charges to Coniston and treatment charges in the reduction works. Considerable saving of metal has already been accomplished by the screening and hand-picking which follow the preliminary crushing of large rock which formerly was trammed directly to the rock dump. When the arrangements now making are completed,

the loss will be considerably less. The present crushing, screening, and handpicking of rock, and the additional arrangements now being completed, are based on tests undertaken by the writer at different times, which proved that the recovery, when the additional plant is working, will be about 94% of the total metal hoisted. At the same time the rock discarded will be about 60% of the total hoisted.

When it is remembered that final crushing is only to 1½ in. size, these figures show the coarseness of the differentiation between rock and sulphide in this mine, and to what extent the ore concentrates before fine grinding has to be resorted to.

The power-house is equipped with a 2044 cu. ft. displacement Ingersoll-Rand compressor, driven by a 350 h.p. alternating current motor. Space is provided for a second compressor should it be needed to keep up the production. The hoist is of the Allis-Chalmers split drum type with two drums; each drum is 7 ft. in diameter with a 6-ft. face, and is capable of holding 2000 ft. of 1¼-in. cable in two layers. Clutches and brakes are controlled by air engines. The hoist is driven by a 250 h.p. alternating current motor, which is capable of hoisting loads of 4 tons in balanced skips at 650 ft. per minute.

UNDERGROUND CONTRACT SYSTEM

Much of the underground work at this mine has been done by miners working on contract. This system has been used almost continuously except during part of 1915 and 1916, when the standard daily rate of pay system was followed because it was favoured at some of the other mines of the company, and was being finally tried to a conclusion.

Under this contract system a group of men is selected and given work on a contract whenever a new section of the mine is ready to drive. This selection is made from those willing to work on contract who are available at the time. It is made dependent upon a man's length of service at the mine and the fitness he has shown for the kind of work to be done. Each man chosen for a contract can expect to continue in it, so long as his work is good, until it is completed.

Standard rates per unit are paid for all drifting, raising, shaft sinking, etc., done under similar conditions. These rates are the average unit cost of each kind of work when done by competent miners, earning the standard, company-account rate of wages prevailing at the time. The total monthly earnings of the different contracts are based on these rates and on the surveyor's calculated volume of ore broken in stopes, and measured footage made in drifts, raises, shafts, etc. From the total earnings is deducted cost of all supplies used by the miners on each contract. The result gives the net earnings due on the contract, which amount is divided by the total shifts worked so as to give the daily rate at which each man is to appear on the monthly payroll.

The contract system has worked satisfactorily at this mine for both employer and employee. It has helped to raise the quality of the labour above the former average standard. When the advantages of the system were first discussed it was claimed that the miners of the district would not work on contract; now, however, at this mine, since the system has been persistently applied, and the miners have been influenced to work by it, most of them have learned to prefer it to the standard rate system, under which the indifferent and less productive worker often shares equally with the more productive workman, and under which the ambitious miner has only his few chances (by promotion) to increase his earnings by better work.

Under the contract system miners have largely within their own control that in which they are most interested, namely, their earnings, with all that results therefrom. Thus a natural incentive is present at all times, influencing them to go ahead steadily, saving what they should for supplies, taking full advantage of their time, improving their work, and promoting their employer's interest as well as their own.

The writer desires to express his appreciation of the assistance of Mr. H. A. Steven and Mr. C. A. Smith in completing drawings and photographs accompanying this paper.

THE GROCH FLOTATION MACHINE

By F. O. Groch and W. E. Simpson

(Annual Meeting, Montreal, 1918)

Before describing any particular flotation machine and the principle on which it operates, it might be advisable to summarize what little is at present known of the general principles

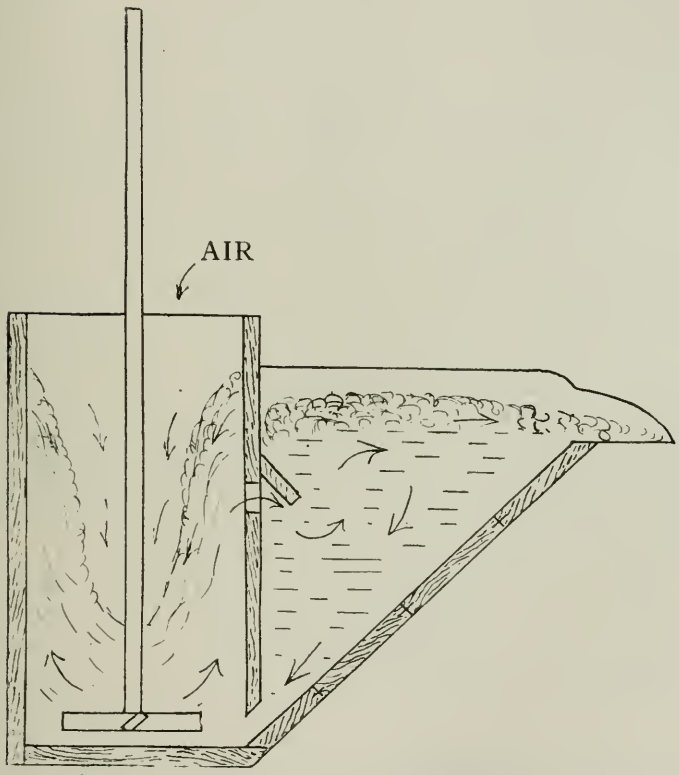


Diagram illustrating action of the Blade Impeller type of Flotation Machine.

underlying successful flotation work so as to better understand the lines of reasoning that may have led to the development of this particular invention. So much has, however, already been

written on flotation generally and so widely is the process being studied that in this paper anything more than a mere formal introduction to the subject is unnecessary.

Flotation is of two classes: (1) the surface film or dry-ore class, in which the ore in a dry state and crushed to the requisite fineness is gently placed on the surface of slowly moving water, a separation being effected because of the tendency of valuable mineral particles to resist being water-wetted and remain on the surface while the valueless gangue particles sink; and (2) froth formation or the wet-ore class of flotation in which advantage is taken of the comparative ease with which the valuable mineral particles already wetted repel or shed the water from their surfaces under the mysterious influence of some froth-forming agent, generally an oil, and attract bubbles of air or other gas with which they may come in contact, forming, in the pulp in which they are immersed, a buoyant association which rises to the surface as a froth or scum. The Groch appliance is of the froth-forming type.

Froth-forming flotation machines may be considered as of two kinds, distinguished from each other by the method employed in bringing the air or other gas into contact with the flotative minerals. The pneumatic machines aerate the pulp under treatment through canvas floors, while the mechanical appliances perform the same function by means of impellers. The Groch machine is of the impeller type.

From the metallurgical standpoint, the best results are obtained when the three essential constituents of a flotation froth, namely, the oil, the air, and the mineral particles are all in a minute state of subdivision; but, for commercial reasons, it is advisable to avoid excessive pulverizing of the ore, not only on account of the prohibitive cost entailed, but also because of the difficulty of profitably disposing of an extremely fine product having the smelter as its only destination. As regards the oil and air, however, no such disadvantage exists, the object of all flotation machines being, in fact, to disperse and subdivide these to the greatest extent obtainable. In this operation the Groch system is especially efficient.

The Groch centrifugal flotation machine may be described as a number of impellers operating in a "V" box 14 feet long by 5 feet wide and divided both longitudinally and transversely into compartments. By means of submerged and slotted partitions, the pulp during treatment is made to take a zigzag course both vertically and horizontally in its passage through the machine. A cross-section shows three compartments, in the

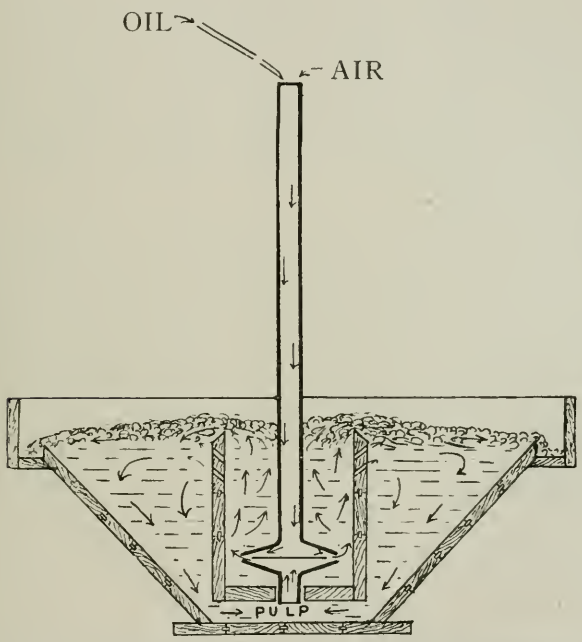


Diagram illustrating action of the Groch Flotation Machine.

central one of which operates the centrifugal impeller which is the chief distinctive feature of the invention. Each impeller is a vertical hollow shaft with, at its lower extremity, a centrifugal 'runner' having hollow hubs and being subdivided horizontally by a metal disc so as to operate after the manner of a pair of centrifugal pumps. This class of impeller combines

the functions of an emulsifier, an agitator, and aerator simultaneously, thereby eliminating any necessity for auxiliary appliances and making each individual machine a complete and independent installation.

During operation, the 'runner' is completely submerged in the pulp being treated, while the hollow shaft, to which it is attached, is the medium through which the power is transmitted to effect rotation. The pulp enters the zone of treatment in the central compartment from underneath a false floor through which the lower hollow hub of the impeller protrudes. It is here sucked up to the interior of the lower section of the 'runner' and ejected centrifugally at the periphery in a horizontal plane, rising upward in the central compartment by the process of displacement until it overflows into the compartments on either side.

All round the zone of discharge at the periphery of the 'runner' a vacuum is created similar to that caused at the nozzle during operation of an ordinary steam injector. With the standard impeller it is found that the vacuum becomes measurable when the speed reaches 200 revs. per min., increasing to a degree equal to 2¾ inches of mercury at a speed of 450 r.p.m. and 6 inches at 750 r.p.m.

Into this vacuum is drawn automatically the contents of the upper section of the 'runner,' and as this part of the impeller has its inlet from the top of the hollow shaft the result is that an enormous supply of air is continuously being ejected as a horizontal layer into the pulp during treatment. This air layer as it recedes from the centrifugal centre must, because of its ever increasing diameter, eventually become so thin as to break up into a shower of infinitesimally small bubbles. According to current theory, this is precisely what is wanted for most effective flotation work.

Through the hollow shaft, also, oil is admitted drop by drop into the area of treatment, each drop falling from a height and, striking the rapidly revolving interior metal disc, becomes dispersed into a state of minute subdivision. To use a trade

expression, the impeller is really an 'atomizer' reducing the air bubbles to molecular size and spraying them with oil, thereby rendering them highly adhesive to the mineral particles with which they come in contact. If it be assumed, as is generally believed, that successful flotation is the result of most intimate mechanical contact between the flotative mineral and the buoying agents, then by this system ample opportunity is given for repeatedly making such associations, for at each impeller the shower of minute air bubbles forms, as it were, a horizontal barrage through which the mineral particles must pass in their passage through the machine. An equal advantage might also be claimed if, on the other hand, it be assumed, as some well-known investigators assert, that the gas bubbles, to be effective, must be nascent or be generated from the solution, each mineral particle becoming the nucleus for the creation of the bubbles in embryo. In the Groch system the air bubbles, being discharged from the impeller at depth, tend to become absorbed in the pulp to the extent of saturation at the pressure to which they are momentarily subjected. With this pulp travelling upward the pressure becomes reduced, and consequently a state of super-saturation must be reached with the liberation of nascent gas bubbles. In any case it would naturally be expected that the union of the gas bubble and the mineral under pressure would be of a stronger type than if no such pressure existed. Once united, the flotative association becomes increasingly buoyant on being brought towards the surface for the reason that, when the pressure is thus released, the buoying gas bubble increases in size through expansion in accordance with well-known natural laws.

The Groch machine eliminates the disadvantage, associated with machines using the blade type of impeller, of having to beat the air into the pulp by the creation of a deep vortex, a system wasteful of power and inefficient in operation. A study of the well-known cream-separator forces us to the belief that, with such a type of machine, the tendency is for the froth or 'cream' of the ore-pulp to collect on the inner surface of the vortex, which is the locality where it is not wanted. Diagrams illustrating these actions accompany this paper.

In this era of flotation enthusiasm, the claim for high recoveries with the production of a clean concentrate seems to be general for all machines, irrespective of their type or the principles on which they operate. It often happens, however, that improvements are effected at a later date rendering work originally claimed as practically perfect still more so. As illustrating one of the best grades of product that the Groch machine can deliver it may be mentioned that, in the case of a molybdenite ore treated experimentally, a concentrate was obtained assaying 99.34% MoS_2, a performance that leaves but little room for improvement, while as regards extractions it is claimed that, in the treatment of a silver ore in Cobalt, a ten days' run with a full-sized Groch machine gave a 5½% better recovery than obtained with other systems, with, at the same time, the production of a higher grade concentrate. A low power consumption is also claimed, the standard machine of six impellers, with a capacity of from 35 to 75 tons per day, depending on the class of ore being treated, showing a consumption of 7½ h.p. by actual determination.

Discussion

The Chairman (Mr. J. E. Hardman): This matter of flotation is an important one from every standpoint. As this Groch machine was conceived by a man in Cobalt and has been developed in that camp I feel sure that any discussion upon this paper will be of great value in the transactions of the Canadian Mining Institute.

Prof. J. W. Bell: Our method of conducting a laboratory test, particularly the putting in of the oil, was a very inefficient one, and I reached a point when I concluded that if we put a tube down to the bottom of the tank and blew the oil into the pulp in that way, it would have been an improvement; but Mr. Groch has improved on that system immensely. He has also devised methods for getting a better distribution of the air and a greater volume of it into the machine through the top of the impeller.

We certainly must congratulate him on the ingenuity of his invention. I hope that it will prove to be a great commercial success.

MR. R. C. CANBY: The Court at Philadelphia decided that a centrifugal pump that sucks in air is an infringement of the Minerals Separation patent. That little disc dividing the centrifugal impeller seems to be the saving grace in Mr. Groch's device because the air is not sucked into any centrifugal pump and there is no violent agitation to produce the froth in his machine. It is the bubbles from the air being sucked in from above that produce the results. I think that, with many users in Canada, there seems to be a strong desire to resist the claims of Minerals Separation, and it is rather interesting that that little piece of iron may become a very important matter in the Canadian courts some day.

MR. SIMPSON: At the National Chemical Exposition in New York, last September, one of the best operators in the United States plainly said to me that if the day came when he would be brought as a witness, he believed that with that impeller he could "make the Minerals Separation sit up."

DR. J. B. PORTER: I would like to add testimony to the extreme importance of this new process. Mr. Bell has been giving virtually the greater part of his time during the past two years to a careful study in the McGill laboratories of flotation, and at McGill we are at present working with the assistance of a special scholarship man, subsidized by the Advisory Council, and are virtually giving the whole of our time and power, so far as our limited resources go, to research work along flotation lines. That is an indication of the University's appreciation of the fact that it is an extremely important line of work.

This piece of apparatus offers a happy solution of one of our difficulties. It is, in a superficial way, an improvement on the Minerals Separation device. Whether it is patentable or an infringement I am not prepared to say, but it is unquestionably a very valuable improvement in its way, for it will secure a better mixture with a given unit of force than can be obtained with

the same amount of power expended on the original type of machinery. I hope we may be privileged to make use of it at McGill in our experimental work as an alternative to the standard Minerals Separation apparatus which we have been using. The application of the principle of flotation is undoubtedly a most important development in ore-dressing practice, and it has already had a revolutionary effect.

MR. CANBY: The development of this device illustrates how many people may do the same thing along parallel lines. Minerals Separation must feel annoyed that they did not think of Mr. Groch's method. True, they employed a method of forcing a stream of air underneath a disc, but they must be sorry that they did not think of doing it the other way. Last September my attention was called to the fact that a man from Vancouver had devised a very similar method. This demonstrates a point I wish to make concerning the co-incidence of the development of ideas such as these by more than one person almost simultaneously. But why should the man who happened to be the first to think of the idea be granted a monopoly in the matter of marketing it? And that is the evil of the Minerals Separation case. They have proceeded to buy up every patent with a view to imposing their demands on an industry which they have not created.

MR. GROCH: As showing how others experimented on parallel lines in respect to the forcing of air underneath a disc as referred to, I can mention the case of one of the Cobalt operators who tried the experiment of putting a small air jet under each impeller in the hope of improving the work, but as a matter of fact he found that with this addition he had actually reduced his extraction by 5%, for the reason that the bubbles rose through the pulp in big masses. The mere operation of putting air under pressure into the pulp is useless. It is from the centrifugal action in breaking up the air into small bubbles that we get the best results in flotation work.

PROF. BELL: At McGill we had a quarter horse-power motor driving our little machine, and when we desired to increase the speed we found that the motor got nearly red-hot every time we ran it; at present we have a one horse-power motor to drive it.

Certainly to get high speed and get a vigorous mixture of air, the ordinary flotation machine takes a large amount of power.

MR. GROCH: In New York we used a tenth of a horse-power for our laboratory machine and found it quite sufficient.

MR. J. F. HARDMAN: The unique character of this machine appeals to me in that it uses so much less power than a Minerals Separation machine or any other machine requiring power. I am not alluding to the Callow machine, which is of an entirely different type. The advantage is that the air is liberated under fifteen or sixteen inches of water and is given that fine division of bubble to which Mr. Groch has alluded.

THE MANUFACTURE OF FERRO-MOLYBDENUM IN CANADA

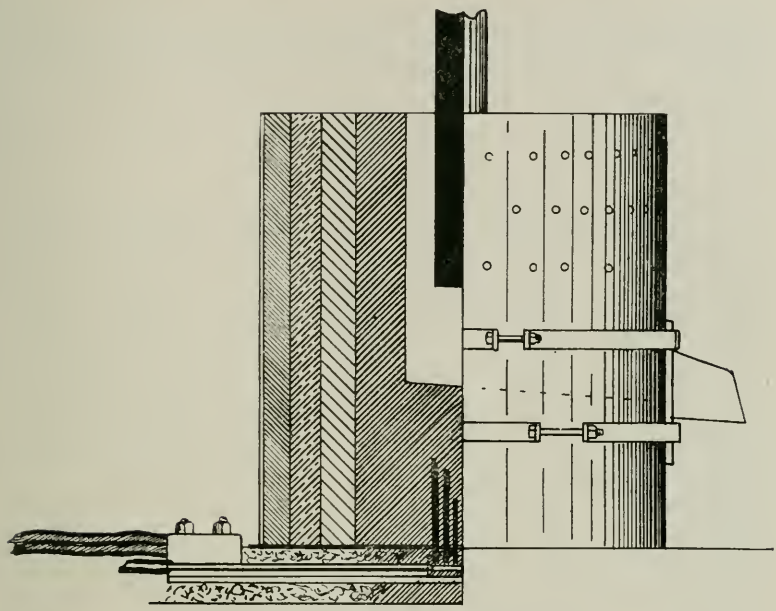
By J. W. Evans

(Annual Meeting, Montreal, March, 1918)

Ferro-molybdenum, made directly from concentrate, was first produced commercially in Canada at Belleville, Ont., on March 23rd, 1916. The molybdenite concentrates being mixed with lime and coke were charged, without previous roasting, into an electric furnace. Since the date referred to, about 100,000 lb. of 70% ferro-molybdenum has been produced for the Imperial Munitions Board at the plant of the Tivani Electric Steel Co., at Belleville.

Originally there were installed at the Company's works two electric-steel furnaces: the one, a two-phase tapping furnace with two electrodes passing through the roof, while an electrode in the bottom of the furnace acted as the common return; and the other, a two-phase tilting furnace, of one ton capacity, with the common return electrode passing through the roof, so that although a two-phase furnace, it had three top electrodes. It was in the first-mentioned furnace, however, that the initial run of 'ferro' was made. The tilting furnace was tried for the making of 'ferro'; but after a continuous heat of 36 hours (during which several tons of steel would have been melted), the silica-brick roof dropped down as if it had been wax; and it was found upon examining the charge that its upper surface only had been melted, and that a few inches below the concentrate and lime had been unaffected.[1] As a result of this experience it was decided to construct a furnace that would be more suitable for the purpose intended. The design as adopted is shown in the accompanying diagram. This furnace, after various changes had been made in connection with the bottom electrode, gave satisfactory results. In the early stages of the undertaking, a production of 100 pounds of 'ferro' from a

[1] The temperature required to smelt molybdenite concentrate is possibly over 1900 C., or greater than is required for the melting of platinum.



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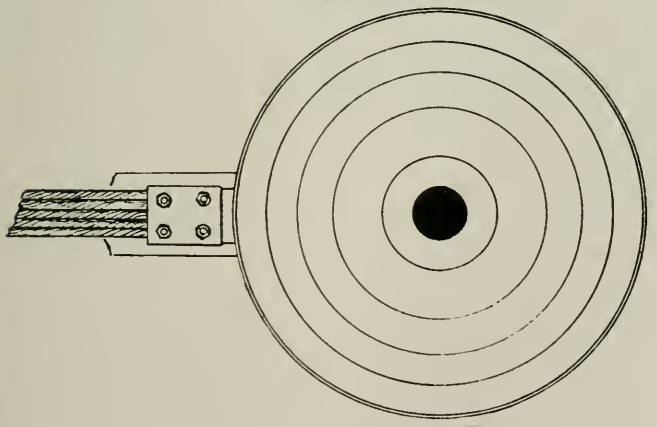

PLAN

10-hour heat was considered to be a good achievement; but this output has been steadily increased, and at present as much as 1,050 pounds of 'ferro' is produced during a 24-hour run.

FURNACES

The furnaces at present in use are of the single-phase type, as the drawing indicates. There are now at the Tivani plant six of these furnaces, each of which employs from 3,000 to 4,500 amperes at 50 volts. The outside shell of the furnace is built of heavy boiler plate in the form of a cylinder, being open at both ends. A series of three-quarter inch holes, at about 12″ centres, are bored in four rows to allow the gases that accumulate within the shell to escape. This shell stands on a concrete foundation which has a trough from the outside to the centre of the shell, in which is placed the connection for the bottom electrode and water-pipes for cooling. The lower electrode is a bronze or copper block 8″ x 8″ x 2½″ with a water jacket. Iron rods of ¾″ diameter are threaded into this block and project up from 6 to 8 inches into the bottom of the furnace. The block is bolted to a heavy copper strip which extends outside the shell, and is connected by an aluminium plate to the cables. At one time heavy carbon blocks were used for the bottom electrode. These extended outside the shell about 12″ for connection to the cable. This construction led to considerable trouble through arching and heating, and was discontinued.

The furnaces are lined as follows: Immediately inside the furnace shell is a circle of red brick. Inside this is a circle of fire-brick, then a silica-brick, and within that the carbon lining. After the brickwork is in place and dried thoroughly the furnace bottom is filled in about the lower electrode. This filling consists of coke and tar heated in an iron ladle. It is built up carefully in layers and rammed as firmly as possible. When the furnace has been filled 12″ above the lower electrode and up to the tap hole, a collapsible form is put in and the lining continued to the top around the form, keeping the lining as level as possible, one bucketful at a time being added until the

furnace is filled to the top of the brickwork. Plugs are inserted in the tap and slag holes. This construction is varied at times by putting in large pieces of waste carbon from the electrodes, when they are available, continuing the bottom through the tap hole to the furnace shell. This makes a satisfactory tapping opening, but the usual rammed lining answers admirably. After the lining is completed, it is left to set for 24 hours, and the form is removed. The tap hole is them trimmed and the furnace filled with coke and burned out for two days. The furnace is then cleared of ashes and clinker and is ready for the initial charge of 100 lb. of concentrates. This is tapped when it is ready; the regular charge of 450 lb. is added in two lots, and the furnace is run steadily, tapping every four hours.

The electrodes are 6″ graphite or 10″ carbon. Rectangular carbon electrodes 12¾″ x 13¼″ are also used. The consumption of graphite and of carbon electrodes is practically the same if measured by their cost. The amount of carbon used per 100 lb. of 'ferro' is more than the consumption of graphite, but the cost of carbon is less than the cost of graphite per pound. A careful account of the weight used both of carbon and of graphite shows practically the same electrode cost. The 6″ graphite electrodes last 24 hours, weigh about 80 lb. and will turn out 1,000 lb. of 'ferro' in that time. The 10″ carbon electrodes last for 50 hours, weigh about 260 lb. and turn out 2,100 lb. of 'ferro.' The electrodes carry from 3,500 to 4,500 amperes at 50 volts.

The furnace charge varies with the grade of the concentrate. A 75% MoS_2 concentrate, carrying 9% iron, will yield a 70% 'ferro' if the charge is made up as follows:—

Concentrate	100 lb.
Lime	120 "
Coke	10 "
Scrap Steel	5 "

The concentrate is assayed for MoS_2 and iron, and the 'ferro' for molybdenum, sulphur, carbon, and silicon. The methods of analyses used at the Tivani laboratory are given below. Sodium

peroxide fusions are employed for the concentrate with lead acetate solution titration, and a weak tannic acid solution as an indicator; while the 'ferro' is treated with 1.20 nitric acid, the iron precipitated with sodium hydrate, and the molybdenum determined by titration with lead acetate solution.

An output of 1,050 lb. of metal in 24 hours does not sound very large; but when one considers that a 75% 'ferro' is worth $3.00 per lb., it will be seen that a product worth $3,150 is a satisfactory daily production for one unit, employing 5 to 6 men on the day shift, and 3 men on the night shift. After operating for nearly two years making 70% 'ferro' on the following specification:—

Molybdenum	70.0%
Sulphur	.4%
Carbon	4.0%

the average of all the analyses on the 100,000 lb. product has been—

Molybdenum	70.43%
Sulphur	.38%
Carbon	3.56%

ANALYSIS OF FERRO-MOLYBDENUM

Sulphur determination. Two grams are taken for analysis, treated with 4 c.c. bromide water and 6 c.c. carbon tetrachloride in a 400 c.c. beaker (Griffin). Cover with a watch glass and allow to stand in room temperature for 10 minutes, agitating occasionally; add 15 c.c. of concentrated nitric acid. Let stand for another 10 minutes, then place on a hot plate and raise the temperature gradually; keep at this point until all is in solution; then evaporate slowly just to dryness; add a small pinch of sodium carbonate and take up in 30 c.c. of concentrated hydrochloric acid. Again evaporate to dryness and heat slowly from 1 to 2 hours to dehydrate the silica. Take up in 20 c.c. of concentrated hydrochloric acid, dilute with hot water to 85 c.c.,

and filter the clean solution into a one-litre beaker; wash well with hot water, cool the filtrate and dilute to 700 c.c. To the cold solution add slowly 15 c.c. of a 10% solution of barium chloride. Decant the solution through an ashless, folded, 11 c.m. filter; wash the precipitate in the beaker with a little warm dilute hydrochloric acid (one of acid to 3 of water), finally transfer the precipitate to the filter and wash well with warm water. Place the filter with the precipitate in an alundum crucible in a muffle and ignite and weigh. If the solution becomes cloudy before adding the barium chloride solution, clear with a drop or two of hydrochloric acid.

Carbon Determination. Burn two grams of finely divided 'ferro' in a stream of oxygen in the combustion furnace, using 4 grams of red lead mixed with the 'ferro' if the silicon is high.

Silicon. The silicon from the first filtration in the sulphur determination is burned; the residue is fused with sodium carbonate and a little potassium nitrate in a platinum crucible, the melt is dissolved in water, made slightly acid with hydrochloric acid, evaporated to dryness, taken up in water and a little hydrochloric acid, filtered and washed. The filter is placed in an alundum crucible and ignited in the muffle and weighed; this residue is placed in a platinum crucible, hydrofluoric acid and a little sulphuric acid added, and evaporated to dryness. The difference in weight being silica, this is calculated to silicon.

Molybdenum. Half a gram of 'ferro' is treated with 50 c.c. of 1.20 s.c. nitric acid, heated till all is in solution, diluted with water, caustic soda added to precipitate the iron; the solution is brought to the boiling point, carefully stirring to prevent bumping, and is allowed to stand until the precipitate settles; it is filtered, washed with hot water, the filtrate transferred to a half-litre measuring flask, cooled to room temperature and made up to the half-litre mark. 100 c.c. of this thoroughly mixed solution is taken in a pipette, placed in a 300 c.c. flask, a small piece of litmus paper added, and hydrochloric acid until just acid; then ammonia is added until just alkaline, and acetic acid until just acid. The solution is heated to boiling, and titrated while hot with a standard solution of lead acetate,

using a dilute solution of tannic acid as an indicator. Standard lead acetate solution is made by dissolving 15.7 grams of lead acetate per 1,000 c.c. water; this is standardized against a 'ferro' of known molybdenum content.

Method for Concentrate. Fuse one gram of concentrate with 25 grams potassium bisulphate in a covered fused-quartz crucible in a muffle at a temperature of between 900° and 1000° C. When fused, place the crucible in a 600 c.c. beaker, cover with hot water and bring slowly to boiling point. When all is in solution, rinse the crucible and cover, and precipitate iron with caustic soda; bring to boil and filter through a folded 15 c.m. filter into a 600 c.c. beaker. Wash four times with hot water, transfer filtrate to a 500 c.c. measuring flask, cool and dilute to mark, shake well and withdraw 100 c.c.; transfer to a 300 c.c. flask and make slightly acid with hydrochloric acid; then slightly alkaline with ammonia, and then slightly acid with acetic acid; heat to boiling, and titrate with lead acetate solution, using dilute tannic acid as indicator. The colour will change from a deep orange to a colourless drop; read the last trace of colour. Dissolve the iron precipitate in hot dilute hydrochloric acid, reduce with stanuous chloride, and titrate for iron with potassium dichromate solution. Time 55 minutes.

DISCUSSION

MR. BRADLEY STOUGHTON: We know that the Germans are using this material in the lining of their very big guns, and some of the Allies are also using molybdenum for this purpose, but in the United States it is hardly used at all. If Mr. Evans has any information as to the uses to which this material is put it will be of value.

MR. EVANS: Ferro-molybdenum was first used, I believe, for the linings of big guns in Russia. Tungsten was originally used for this purpose, but it was found that it did not stand the concussions as well as the ferro-molybdenum, and 50% of

what we manufactured was sent via England to Russia. The belief of many officials of the Imperial Munitions Board was that it was sent to Russia for rifling the large guns at Riga.

MR. STOUGHTON: Is it used for high speed steel ?

MR. EVANS: It is not used in this country for high speed steel so far as I know, but manufacturers are using about a 3% ferro-molybdenum and making a mild steel which will stand the same contortions and twisting as nickel steel.

MR. COLVOCORESSES: I understand that the steel mentioned is employed in the manufacture of automobiles.

MR. EVANS: I believe they are using it extensively in the Ford manufactory for axles. It is said ferro-molybdenum was used in England before ferro-tungsten. I was told by a man in our plant that he had seen it used there 30 years ago, but its use was discontinued because molybdenum was not obtainable.

WASTE OF COAL IN CANADA

By W. J. Dick

(Annual Meeting, Montreal, 1918)

All the civilized and progressive nations of the earth are today anxiously taking stock of their resources. They have found that the practice of trusting to others for the necessities of civilized existence is fraught with danger and uncertainty. They have learned that a nation can only surely count on that which lies within its own borders and that is capable of being guarded against forcible exploitation by enemies.

Value of Coal

Day by day it becomes more evident that coal is the mainspring of modern material civilization—it has of late years been found to yield by-products of inestimable value, supplying gas for heating, lighting and industrial purposes; products forming the basis of the aniline dye industry; various chemical products for use as fertilizers, disinfectants, drugs, and explosives. Its importance to a nation has been well exemplified in the present war. Without it Germany could not have carried on the war as long as she has, and according to Ludendorff the success of the German drive in Italy was due in a measure to the shortage of coal in the latter country.

Let us see for what purposes coal has been used in the present war:

(1) As a source of power;
(2) for metallurgical purposes;
(3) as a source of tri-nitro-toluene explosive;
(4) as a source of picrite acid for the manufacture of lyddite and melinite explosives;
(5) as a source of ammonia for the manufacture of
    (a) Ammonal explosives,
    (b) nitric acid,
    (c) fertilizers;
(6) for the production of benzol as a fuel for use in internal combustion engines.

The value of coal has not yet been fully realized, and the progress of science and the improvement in the arts will tend to increase the supremacy of steam and coal. While hydro-electric energy will replace it to a certain extent in Canada, the dependence of numerous industries upon coal and coal products for their raw materials ensures that coal will always be required on a large and increasing scale. Upon the exhaustion of the oil-wells all the petroleum products which are now obtained from them must, as far as possible, be obtained from products distilled from coal.

Waste of Coal in Canada

The coal reserves of Canada have been shown to be very large and the production relatively small. However, Canada is still in the earlier stages of industrial development. The principal coal reserves of the Dominion are situated in the interior and remote from present transportation facilities, leaving a small portion on the Atlantic and Pacific seaboards available for export. Notwithstanding the virgin character of our coalfields, we are greatly handicapped at the present time by the high cost of producing and shipping our coal. As most of our coal is remote from transportation and not now available, only the exercise of careful conservation will enable us to keep the price, and therefore the more universal use of coal, near present levels. The gradual deepening of our coal mines and the opening up of new mines in less favourable localities than at present cannot but increase the price of coal and thus effect changes in our industrial condition. It is not proposed that we should interfere with the free use and development of our coal resources, but that our duty lies in the earnest and wise application of knowledge to their development and use. The wasting of this valuable asset is not only an economic loss to ourselves, but it is the means of placing a burden upon our national life which can never be removed.

To conserve the coal in the developed areas, and also to prevent the economic waste through the added cost necessary to develop new areas, all waste of coal should be reduced to a minimum.

At the present time, a large proportion of the coal is lost or wasted. The waste of slack coal is small in comparison to coal left in as pillars or to the loss of whole coal seams through caving of the measures.

The largest reserves of coal in Canada are situated in Alberta, Saskatchewan, and British Columbia. The unalienated coal resources of Alberta and Saskatchewan are held by the Dominion Government, whose duty it is, therefore, to protect these rights or the public.

CAUSE AND NATURE OF WASTE AND HOW IT MAY BE ELIMINATED

The cause and nature of the waste of coal in Alberta and Saskatchewan may be classified in order of importance as follows:

(1) The method of disposition of coal lands;
(2) Loss of coal due to actual mining operations, pillars lost through crush, etc.;
(3) Waste of unmarketable slack coal;
(4) Waste of by-products due to method used for coking coal;
(5) Waste through present method of use of coal.

(1) DISPOSAL OF COAL LANDS

The coal-mining rights on Dominion lands are disposed of under lease by the Federal Government. The provisions of the lease are liberal and such as to encourage coal-mining. Leases are granted according to priority of location, but no consideration whatsoever is given to the relation of coal seams, quality of coal in the several seams, order in which seams are to be worked, or total coal content contained in the area leased.

In the coal areas of Western Canada there are usually a number of seams quite close together, and, should the lowest seams be the most desirable with regard to quality and ease of working, there is nothing to prevent the operator from mining them first. In fact, this practice is now being followed in a number of cases in the West. As a result, caving of the measures will, in most cases, render it impossible to recover the coal from

the upper seams. Owing to the wide distribution of coal, and as leases are granted to anyone desiring to mine it, the operator who looks to the future and mines the coal in a systematic manner carries on his operations at a higher cost than the operator who takes the easiest available coal. There is, therefore, no inducement to use other than wasteful methods. For instance, in a certain mine, owing to a great demand for coal, the directors instructed the manager to produce an output greater than the development work justified. The mine-manager was forced, against his better judgment, to obtain the coal wherever he could. Some pillars were extracted and others were reduced to such dimensions that they were not able to bear the weight of the superincumbent strata As a result, there was a 'squeeze,' and to-day the mine is badly wrecked and much coal has been lost.

All other important coal-mining countries which dispose of coal-mining rights under a system of leasehold have found it necessary to prevent waste arising from the lessees sacrificing the public wealth for their private gain and from waste due to injudicious mining. In Nova Scotia, Austria, Australia, and Japan, and in respect of privately owned coal lands in England, Scotland, and in certain portions of the United States, before a lease is granted or mining operations are begun, the applicant or the holder of a mining right is required to submit a scheme of intended operations to the proper authorities, which scheme is approved only if it is designed to prevent wasteful mining and at the same time provide for the safety of the miners.

The system of indiscriminate leasing of coal lands tends to increase the waste of coal. At the present time there are more leases issued than the conditions of the coal-mining industry warrant. The revenue derived from royalty on coal from leased lands in these provinces for the year March, 1916, to March, 1917, was as follows:

Alberta	$149,447
Saskatchewan	2,200

The total revenue comprising royalty and rentals in Alberta and Saskatchewan amounts to $325,000.

Assuming that the royalty was 5 cents per ton, $149,447 would represent a production of about 3,000,000 tons from leased lands. In other words, 75% of the present production of coal from these provinces is derived from leased lands. The number of leases in effect in Alberta is 600, comprising an area of 304,606 acres; in Saskatchewan there are 92 leases comprising an area of 5,300 acres, making in all a total of some 700 leases, comprising an area of about 310,000 acres. There are 250 mines now in operation producing 3,000,000 tons per annum. If these mines were worked to their capacity the output would be increased five-fold, or in other words, from 15,000,000 to 16,000,000 tons would be produced per annum. This fact is of importance when it is considered that the actual production of coal in Alberta and Saskatchewan does not exceed 5,250,000 tons. In 1912 there was in effect the maximum number of leases issued, but since the exaction of a rental or $1 per acre per year the area under lease is gradually diminishing year by year.

(2) WASTE IN ACTUAL MINING OPERATIONS

This waste is represented by:

(a) Non-recovery of pillar coal;
(b) Mining of portion of seam only;
(c) Coal lost through opening up and abandonment of small or 'snow-bird' mines;
(d) Unnecessary slack made during mining.

(a) *Non-Recovery of Pillars.*—In the steeply pitching and frequently faulted coal seams of the Rocky Mountains, where the cover over the coal varies from zero to several thousand feet, it is difficult to recover all the pillar coal, but this waste would be reduced to a minimum if a proper and systematic method of mining was carried out.

The longwall method of mining is such as to produce the highest recovery of coal and at the same time reduce the per-

centage of slack to a minimum, but conditions are not favourable to its general introduction in Western Canada.

Conditions affecting the adoption of this method are:

(1) Condition of roof;
(2) Attitude and thickness of coal seam;
(3) Labour;
(4) Market.

(1) *Condition of Roof.*—The roof conditions in Western Canada are not favourable to the adoption of the longwall method, as the roof is in general brittle and breaks without bending on placing a gradual weight upon the coal face.

(2) *Attitude and Thickness of Coal Seam.*—Conditions favourable to the longwall method are a comparatively flat seam without great irregularities, of great thickness, and with considerable cover. Such conditions are comparatively rare in Western Canada.

(3) *Labour.*—Longwall mining is carried on to a considerable extent in England, Scotland, and on the continent. The work is done by men skilled in this method of mining. The class of labour available for operation of mines in Western Canada is such that in general it might be said that they are not experienced in this method, or even any kind of mining. Even in Nova Scotia, where mining has been carried on for a number of years and a skilled class of miner produced, it has been found difficult to introduce this method; for example, at one mine it was necessary to send to Belgium for men familiar with this method.

(4) *Market.*—Longwall mines require to be in operation continuously so that an even uniform pressure may be kept on the coal, and the longwall face maintained. In Western Canada the demand for coal is principally during winter and spring months, so that this factor is not favourable to the employment of this method.

(b) *Mining of portion of Seam only.*—Sometimes the seam is so thick that it is not possible to remove the whole seam at one lift, and only the better portion is mined; or the nature of the roof is such that it is necessary to leave in some top coal to form

a good roof. Also, the coal seam may be divided by rock bands or dirt 'partings' which are of such a character that it does not pay to remove more than a certain portion of the seam. Thus, this may, at present, constitute an unavoidable waste; but, so far as the value of such coal to the country is concerned, it would usually be more economic to refuse the leasing of such an area at the present time.

(c) '*Snow-bird Mines.*'—The demand for coal during the winter causes the opening up of 'snow-bird' mines. These mines, situated in the lignite or sub-bituminous fields, have a small production and operate for a few months during the winter. The loss of coal through the opening up and abandonment of farmers' or 'snow-bird' mines has been considerable. For example, some mines on the Red Deer and other rivers, or situated on deep coulees, are opened up as follows: The seam outcrops say 15 to 20 feet above water level, and some 500 feet in from the outcrop the cover over the coal may vary up to say 300 feet. An entry is driven from the outcrop and a few rooms are opened off from it. The workings are timbered with poplar, which does not last longer than two years, when it gives way, and as a result the workings are caved. It does not pay the small operator to clean up the old mine and re-timber it, so that a new mine is started a short distance from the old one. A continuation of this practice will destroy the entrance to the coalfield lying back from the river. In the future, when it is necessary to develop the field on a large scale, it can be done only by means of an expensive shaft.

About 400 mines have been abandoned in Alberta alone, nearly all of which are farmers' or 'snow-bird' mines. The province of Alberta requires that mine plans be kept up to a date not more than three months previous, and that the work be done by a qualified certificated mine surveyor. It is also provided that barrier pillars of sufficient width be left between the working of abandoned mines and new mines. Unfortunately, the plans of a number of the abandoned mines do not exist, and unless great care is exercised these mines will prove a menace to future operations, as the workings of some of them are below water level and are filled with water. As illustrating the

danger that may arise in connection with mining operations carried on near abandoned mines, it may be cited that in 1915 nineteen lives were lost through the water breaking into the workings of a mine on the Pacific Coast from an abandoned mine.

(d) *Slack from Mining Operations.*—Slack is produced during the mining and handling of the coal. As there is a limited market for the slack a great proportion of that produced is wasted unless supplied as run-of-mine. The largest proportion of the slack produced in mines of Western Canada is due to the use of excessive amounts of explosives. This is an avoidable loss, and closer supervision would be the means or reducing it to a considerable extent. It may also be reduced by the use of mining machines and by care in handling the coal.

(3) Waste of Unmarketable Slack Coal

In some of the semi-anthracite mines and in practically all the sub-bituminous and lignite mines, the proportion of coal wasted as slack varies from 12% to 35%. The slack made in coal mining operations in the Crowsnest Pass district is usually coked in beehive ovens, but there is only a limited market for the coke, and the freight rates make it impossible to market the slack coal to advantage. There are a number of seams of coal (often upper seams) which at the present time cannot be worked on account of the large percentage of slack made during mining, but which could be worked to advantage if there was a ready market for the slack.

The solution of the problem of the economic disposal of slack coal would be brought about by the manufacture of briquettes, but the industry cannot become possible until a sufficient supply of a cheap binder is available. Several binders have been used in the manufacture of coal briquettes, but the most desirable one, and the one most widely used, is tar pitch. The pitch is a by-product from coal tar removed from by-product coke ovens. In California, Arizona, and other portions of the West, asphaltic pitch, the residual product from refining of the heavy asphalt base petroleum of that region, has been, and is now, successfully used in briquetting plants. There are enor-

mous deposits of tar-sands on the Athabaska river, and on development of these there will be made available a large supply of pitch which will probably be suitable for briquetting purposes. On account of the great importance of this question to Western Canada it is desirable that everything possible be done in order that the slack be made into a marketable product and not wasted as at present.

The raw lignite of Saskatchewan contains a high percentage of moisture, and if exposed to the air for a short length of time it slacks and disintegrates. It also ignites readily through spontaneous combustion. These defects, together with the cost of freight on an inferior coal, preclude its shipment for any great distance and prevents its storage for winter supply. It may be used successfully with mechanical stokers for the generation of steam in boiler plants. It is also of value as a source of power in producer-gas plants The present market for this coal, however, is for heating and power purposes during the winter months when, owing to freight conditions or to severe weather, coal cannot be had from Alberta or United States.

The proper utilization of the slack and low grade fuels of Alberta and Saskatchewan will not only prevent their waste, but at the same time solve the domestic fuel and cheap power problems of the Prairie Provinces. In order to make this fuel transportable and suitable for domestic and power purposes it would be necessary:

1. That it be of sufficient value to bear the cost of transportation;
2. That it withstand handling and a certain amount of weathering;
3. That it be a suitable fuel for domestic and power purposes.

Coal or lignite briquettes and carbonized lignite briquettes fulfil these conditions.

In view of the importance of this subject it is desirable that investigations be carried on to hasten the introduction of proper methods for utilizing these fuels. An investigation[1] un-

[1] Carbonising and Briquetting of Lignites—Economic Possibilities, by W. J. Dick, *Commission of Conservation*, 1918.

dertaken by the Commission of Conservation shows the economic possibility of manufacturing a high-grade fuel from the lignites of Saskatchewan. Carbonized lignite briquettes are stated to be practically equal in heating value to anthracite coal. They will, therefore, stand comparison very closely on the basis of cost. An examination of the table given below will show that the difference in favour of briquettes as compared with anthracite coal varies from 45 cents per ton at Portage la Prairie to $2.50 per ton at Moose Jaw. This allows a profit of $1.00 per ton to the producing plant. Such a plant with a capacity of 30,000 tons would represent a capital expenditure of $400,000. The yield on the investment would be, therefore, 7½ per cent. Even by the installation of one plant, the lower price of briquettes would mean a large saving to consumers in western Manitoba and Saskatchewan, and some $225,000 would be kept annually in the country instead of being paid to American coal producers.

	Tons of U.S. anthracite used in 1916-17	Price of U.S. anthracite per ton f.o.b. *	Carbon Briquettes: Freight rate and switching from Bienfait	Carbon Briquettes: Estimated cost f.o.b. cars	Carbon Briquettes: Selling price profit of $1.00 per ton f.o.b. cars	Difference in favour of carbon briquettes
Winnipeg	200,000	$9.50 to $10.00	$1 90	$9.15	$10.15	
Portage la Prairie	4,000	10.00 " 10.50	1.80	9.05	10.05	$0.45
Carberry	1,050	10.65 " 11.15	1.60	8.85	9.85	$0.80 " 1.30
Brandon	9,200	10.60 " 10.85	1.50	8.75	9.75	.85 " 1.10
Virden	2,280	10.80 " 12.15	1.60	8.85	9.85	.95 " 2.30
Moosomin	1,836	11.00 " 12.25	1.80	9.05	10 05	.95 " 2.20
Wolseley	1,012	11.50 " 11.75	1.80	9.05	10.05	1.45 " 1.70
Regina	45,300†	11.60 " 12.25	1.60	8.85	9.85	1.75 " 2.40
Moose Jaw	3,845	11.45 " 12.35	1.50	8.75	9.75	1.70 " 2.50

* Owing to the exhaustion of the anthracite resources of the United States, these prices will increase year by year.

† Figures supplied by the Secretary, Regina Board of Trade, and unlike the others include coal used for railway purposes, power plants, and manufactories.

Coking of Coal

In 1916, 1,501,835 tons of domestic, and 633,076 tons of imported coal were charged to coke ovens from which was obtained an output of 1,448,782 tons of coke, thus averaging 0.679 tons of coke per ton of coal charged. Coke from by-product ovens comprised 69% of the total.[2]

[2] The Production of Coal and Coke, by John McLeish, B.A., *Mines Branch, Dept. of Mines.*

There are in the Dominion of Canada at present nearly 2,800 coke ovens. Of these, 724 are by-product ovens, 150 are semi-by-product ovens, saving gas only as a by-product, and 1,890 beehive ovens, of which 480 have been abandoned. From the above it is evident that there are about 1,560 beehive ovens in Canada. These ovens yield from 5% to 10% less coke per ton of coal charged and do not save any of the valuable by-products such as gas, tar, ammonia, benzol, etc., which form the basis of many important industries.

In 1916, over 340,000 tons of coke were produced from beehive ovens in British Columbia and Alberta from 516,700 tons of coal. This represents a loss of about $700,000 in by-products alone. The following are some of the economies which may be effected by the use of by-product coke ovens as against the use of beehive ovens; and in this connection it should be noted that the quality of the coke is just as good for metallurgical purposes as coke made in beehive ovens:

1. The yield of coke from by-product ovens is 5% to 10% higher than the yield from beehive ovens.

2. While the cost of installation per oven is greater for the by-product than for the beehive oven, the capacity is from three to six times as great.

3. In by-product ovens, the following by-products are obtained:

(a) *Gas:* The total amount of gas obtained from a ton of ordinary coking coal amounts to about 10,000 cubic feet. One-half of this amount is used to heat the ovens and the remainder, 5,000 cubic feet, is recovered as a by-product. The gas has an average value of 500 B.T.U. per cubic foot. It can be used for firing under boilers, metallurgical purposes, operating gas engines, illuminating purposes, cooking, or for any other purpose for which coal gas may be employed. If used in gas engines, about 250 horse-power hours can be obtained from the surplus gas from one ton of coal.

(b) *Ammonia:* From 20 to 24 lb. of ammonium sulphate is obtained to the ton of coal charged. This has a value of from 2½c. to 3c. per lb. above the cost of manufacture. The ammonia may be recovered either as ammonium sulphate, which may be

used for fertilizer, or in the manufacture of nitric acid by the synthetic method, or as a concentrated liquor for refrigeration purposes.

(c) *Tar:* This amounts to from 7 to 9 gal. per ton of coal charged and is worth from 2 to 3 cents per gallon in the crude state. It is worth much more if distilled, creosote, light oils, carbolic acid, and pitch being recovered. Creosote is used for the preservation of timber. Pitch is used for paving, waterproofing, and as a binder for the manufacture of coal briquettes. The amount of pitch recovered from one ton of coal varies from 50 to 67 lb. In other words, the pitch recovered from one ton of coal is sufficient to briquette one-half of coal briquettes.

DISCUSSION

Mr. G. G. LINDSEY: The question of whether it would pay to briquette the inferior lignites of Saskatchewan is referred to by Mr. Dick. This matter has received the consideration of the Honorary Advisory Council for Scientific and Industrial Research, which has proposed to the Government of Canada that money be provided for the establishment of a plant to manufacture this product on a commercial or semi-commercial scale. The utilization and marketing of Saskatchewan lignite, and for that matter the disposition of coal from any locality in the country, hinges entirely on the question of transport. Of course, if the coal is of good quality it can be carried a long distance, whereas a coal of poor quality cannot be transported any distance to commercial advantage. Because of this we were obliged in 1916 to import from the United States 2,118,000 tons of bituminous and 258,000 tons of anthracite coal. If I understand Mr. Dick aright the problem he presents for solution is how to utilize our own fuels so that money now spent in the purchase of coal from the United States can be retained in Canada. Apparently he has not attempted at all to deal with a most important phase of that problem of how to save the bringing in from the United States of the 2,118,000 tons of bituminous coal, but has confined himself to dealing with the practica-

bility of replacing the imported anthracite by providing an equivalent in the form of briquetted fuel from Saskatchewan lignites. It seems to me that if that larger question could be solved that the problem as a whole would be solved. Why is this large quantity of bituminous coal imported from the United States? Because it pays the railways to so direct it. The empty car movement from the head of the Great Lakes is westward. The full car movement to the head of the Great Lakes is eastward, and everybody who has had any experience in practical mining and in the handling of coal in Western Canada knows that the difficulties in connection with the marketing problem are those of transportation, namely, adverse freights and shortage of cars. In other words, the question is one of replacement. What produce or goods can the railways carry westward in the place of the imported bituminous coal? I would urge on those who seem to have this problem so much at heart that they should consider it from that standpoint. There are a very great many kinds of coal in the Canadian West. They range from inferior lignite in Saskatchewan to the very highest grade of bituminous coal obtainable in America, and the grade improves steadily as you approach the summit of the Rocky Mountains. In Saskatchewan the coal is of the poorest grade, while that mined at the summit of the Rocky Mountains is the best, and will compare favourably with the very best coal that obtains in the bituminous field of this Continent. These coals will stand transportation, and they make very little slack; what slack they do make can very profitably be converted into coke, and there is a market for every ton of such coke. Why then do we bring coal to the prairie provinces from the United States when in our own country we have a better coal that we might deliver to that Canadian market at a lesser cost? The freight rate from the summit of the Rocky Mountains to Winnipeg is $4.50, and with the price of coal at $3 it could be laid down in Winnipeg for $7.50, and at intervening Saskatchewan and Manitoba points at less prices, depending on freight rates; and this, moreover, is a better coal than can be obtained from the United States for the same money. Why then is not that market open to Canadian producers? The answer is—because it has not suited the

railways to favour it for the reason already mentioned—that the empty car movement is westward and the full car movement is eastward. As to the proposal to briquette the inferior lignite coal of Saskatchewan to replace what represents a comparatively small proportion of imported anthracite, this expedient it seems to me is needless if, as I have suggested, high-class bituminous coals from Western Canada are made available in the market referred to at a lesser price than either anthracite or the proposed manufacture fuel. Nevertheless, Mr. Dick is entitled to a discussion of the case he puts forward. I would therefore like to ask him whether, in making the calculation as to the amount of lignite coal required to make a ton of briquettes, the samples on which his figures are based were taken from the mine or did they represent air-dried coal ?

Mr. DICK: From the mine.

Mr. LINDSEY: On page 4 of Mr. Dick's report entitled "Carbonising and Briquetting of Lignites," issued by the Conservation Commission, the price and value of the briquettes are based upon data copied from Bulletin 89 of the U.S. Bureau of Mines, "Economic Methods of Using Western Lignite." That statement has reference to the lignite as mined in Dakota, which coal contains 35% moisture, 25% volatile matter, 34.67% fixed carbon, and 5% ash, and has a heating value of from 7,000 to 7,800 B.T.U. After briquetting, a product is obtained containing no moisture, 2% to 8% volatile matter, 72% to 82% fixed carbon, and from 10% to 16% ash, and having a heating value of from 11,500 to 12,000 B.T.U.

The value of a coal depends on its heating value, and the calorific of our western Rocky Mountain coal is higher than any anthracite coal you can bring from the United States of America. But the comparison here is between the imported anthracites and the carbonized lignite briquettes that it is proposed to make in Saskatchewan. If it can be demonstrated that briquettes cannot be made cheaper for the same calorific value, then the briquettes are made in vain. There are four anthracite fields in the United States, namely, the northern, the eastern, the middle west, and the southern anthracite coalfields. The standard analyses show that the fixed carbon content of these

coals are in the relation of 83%, 86%, 81%, and 83%, and that their calorific value in terms of British Thermal units are 13160, 13420, 12840, and 13220 respectively. It takes, we are told, two tons of Estevan coal to make one ton of substitute anthracite, and the cost calculation is made on that basis according to the Conservation Commission's report. I think, however, it must require more than two tons of lignite. I call attention to the information presented on page 22 of the Report. The fuel as received from the mine at Bienfait has a fixed carbon content of 32.7%. By driving off the moisture and volatile the carbon content is doubled to 65%. But 65% is a long way short of 83%, and does not place this product in a class with anthracite. It is not an anthracite coal, nor is it even a high-grade bituminous coal. Hence, the gentleman who read the Annual Report (1917) of the Royal Society, no less a person than the Chairman of the Honorary Advisory Council for Scientific and Industrial Research, presented the truth in the following statement therein with reference to the results of the briquetting operations: "The Council, however, believes that by a special treatment there may be produced from this lignite two grades of high class briquetted fuel, one similar to anthracite or hard coal in character and the other resembling soft coal in character." In other words, there will not be substituted for the anthracite of the United States a product equal to anthracite, but one equal only to a bituminous coal which it resembles—a product containing a carbon content of 64% compared with the average carbon content of the anthracite it is to replace of 83%. The proposal, therefore, is to make an artificial bituminous coal of composition and calorific value inferior to the high-grade bituminous coals of Western Canada that can be supplied to the same market at a lower price.

An examination of the analyses of other Saskatchewan lignites is illuminating. For example, the analysis of coal from the Shand mine shows fixed carbon 30.7%, volatile matter 24.5%, moisture 34.8%, and ash 10%. Multiply the fixed carbon by two, and the result is 61% only. The analysis of coal from the Estevan mine (sample No. 1079) gives fixed carbon 28%, volatile matter 26.4%, moisture 35%, and ash 9.7%. The analysis

of the Bienfait coal shows fixed carbon 33%, volatile matter 27%, and ash 5.5%. The briquettes from the former would therefore contain 56% and from the latter 66% fixed carbon, and even the higher result is not equal to the fixed carbon content of the bituminous coals from the summit areas of the Rocky Mountains. Hence, to obtain a briquetted product to equal anthracite it would be necessary to use nearer three tons than two of lignites, in which case all the calculations on which the argument in favour of this proposal is based are nullified. I submit, therefore, that the figures as presented need revision. In short, I fail to understand how the project of briquetting lignites can be justified on any sound basis. If it be argued that by this undertaking the expenditure in the purchase of United States coal will be avoided, the reply is that this can be accomplished by providing that the greater proportion of the imported American coal shall be replaced by cheaper Canadian coal of the same class and of equal quality that is available. All that is necessary is to mine it and to sell it at the same price as that obtained for American coal. If the argument be that the briquetted fuel will equal and can successfully compete with American anthracite I submit that this has not been demonstrated.

Mr. James McEvoy: My attitude towards the Advisory Council is most sympathetic. I cannot help being impressed, however, by some of the criticisms by Mr. Lindsey of the proposal to manufacture lignite briquettes; and I also bear testimony to the high-grade quality of our own fields in the Northwest. At times we conduct tests on the evaporation under actual working conditions of the Crowsnest coals, and we get a 10.67 evaporation; that is, 10.67 pounds of water evaporated into steam under ordinary working conditions per pound of coal. If you refer to your textbooks on the coals of the United States you will rarely find higher results than 9.00. This is good, but 10.67 is excellent. Therefore the question as to the quality of our coals is absolutely settled; we have the highest-grade bituminous coal on the North American continent in our Northwest. I was very much pleased with Mr. Dick's paper, more pleased than I was with his Report for the Conservation Com-

mission, because I thought there was in the former evidence of leaving the question a little open. I admired the candour of the admission that briquettes of the inferior lignites of Saskatchewan cannot compete commercially with our high-grade bituminous coals. That is worthy of consideration by the Advisory Council. If you cannot make briquettes to compete in efficiency with the coals of the Rocky Mountains, then the advisability of doing it at all is open to question. I think another point the Advisory Council might consider is that of conservation. This war is a test of conservation of man-power as well as other resources, and if you have to take two tons of lignite to make one ton of an inferior substitute for anthracite, and in addition have to expend further labour and material to convert it into that substitute fuel, that scarcely seems to represent conservation of energy or of man-power. Surely it would be more economical to replace every ton of imported coal by one ton of Western bituminous coal, which could be done by providing a reasonable freight rate, instead of to accomplish the same end by being obliged to mine two tons of lignite with the subsequent task of manufacturing it. What do we gain ? Possibly, however, the Advisory Council is trying to give the consumer a cleaner fuel, as the briquettes are nicer to handle than bituminous coal. If, in war time, that is a sufficient justification for the undertaking, well and good. But it seems to me that in producing this substitute fuel we may be accused of spending two to three times the labour in order to produce a luxury. Anthracite in the Northwest is a luxury. There are people in San Francisco who have burned anthracite all their lives, although they have had to pay for it from $15 to $25 a ton. It is also luxury in our Northwest and far West, and we should accustom ourselves to using bituminous coal, which can be burned with perfect satisfaction. I have used it in my house furnace, and in mild weather have left it for twenty-four hours without replenishing the fire, which stayed in during the whole of that time. You can burn this fuel in the ordinary domestic furnace designed to burn anthracite. It is being used in Toronto in that way to-day. In my opinion the Government ought to prohibit absolutely the importation of anthracite into the Northwest

during the war as a fad which should not be tolerated. And if that principle is accepted they ought also to prohibit the use of expensive substitute fuels.

Dr. J. B. Porter: Mr. Lindsey says he is unable to understand Mr. Dick's arithmetic, but I think he could understand it easily enough if he had not forgotten his own chemistry, or perhaps the trouble is in the use of the term 'briquetting' to describe the lignite proposals. It is not briquetting at all in the ordinary sense, but partial distillation followed by briquetting, which is a very different thing.

The lignite contains, according to Mr. Lindsey's figures, from 28% to 30% of fixed carbon, but it must not be forgotten that it also contains from 25% to 35% of volatile combustible which is also chiefly carbon, and in addition it contains 25% to 35% of water.

The process of carbonization, of course, drives off all the moisture and a considerable part of the carbon in the volatile matter, but by no means all of the latter, and thus the carbonaceous residue, which is briquetted, contains not only the original fixed carbon, but also additional carbon to an amount depending on the method of treatment.

The case is similar to, but more favourable than, that of coking, in which it is perfectly well known that the yield should be and often is largely in excess of the mere fixed carbon in the original coal.

I have no analyses of Mr. Dick's samples, but the Souris lignites sampled on a large scale for our Dominion Government Coal Investigation a few years ago showed, for example, Taylorville lignite, fixed carbon 42.9% and volatile matter 49.0%, of which 16.9% was carbon, or a total carbon of 59.8%. Similarly the Estevan lignite gave 43.2% fixed carbon, 40.0% volatile matter, with 14.5% of it carbon, or a total carbon of 57.7%. These figures are on the dried lignites, which before drying contained 28.6% and 30.9% respectively of moisture, but even if we allow for the whole of this moisture we get total carbons of 42.9% and 39.7% respectively in the lignite as mined.

In the case of lignites the process of coking and briquetting is

still more or less experimental. I shall explain later why we have excellent ground for expecting to get a very large increase in yield by saving part of the volatile combustible, but we shall have to wait on the completion of just such plants as that under discussion before it will be possible to quote exact figures or to forecast commercial results with certainty.

With bituminous coal the case is very different. I have figures of actual tests made on coking a score or more well-known Canadian coals, and they show increases in yield ranging up to as much as 16% or 17%, and averaging nearly 10% above those provided by the fixed carbon alone; and as it may be contended that these are merely 'tests,' I have obtained permission to quote figures officially given me by the Production Division of the Ordnance Branch of the United States War Department, which show an actual yield in one plant of 73.32% when the fixed carbon would only account for 67.9%, or an increase of 8% in the fuel value of the coke due to this carbon from the volatile matter; and in another case, of an old plant stated not to be in good condition, the yield of a whole year's operation showed an increase of 2½% due to this same cause.

Such results as these are of very decided importance, and may easily turn the balance between commercial success and failure even in a plant making metallurgical coke which must be hard, and therefore practically free from volatile matter. The case in favour of manufactured domestic fuel is very much more favourable, as here the coking is not carried nearly so far and considerable quantities of high-temperature volatile combustible are deliberately retained, thus still further increasing the yield and the calorific value, and incidentally making the fuel much more suitable for household use than either anthracite or straight metallurgical coke. In fact it is quite unfair to the 'briquetting' scheme to assume that its product should be judged strictly on a coke or anthracite analysis basis. It is really a different fuel, more like the celebrated Welsh anthracite than the Pennsylvania article, and judging by briquettes produced elsewhere from coals of approximately the same class we may hope, and I believe expect, that the briquettes will prove

distinctly better for domestic use, at least, than much of the anthracite now marketed in Canada.

Referring to the very high terms in which Mr. McEvoy has spoken of the Crowsnest coals, I think his enthusiasm has led him too far. The Crowsnest coals, or rather the very best of them, are remarkably good, and Canada can well be proud of them, but it is absolutely wrong to speak of them as "the highest grade bituminous coal on the American continent," which they are not, as any trustworthy table of analyses will show. And in this connection it is proper to call attention to one serious defect of these same high-grade Crow coals, namely, their great friability, which causes nearly all of them to yield a relatively small amount of lump and an inordinate quantity of slack. This friability is of no importance where coke is being produced, but it would undoubtedly militate greatly against their value for long distance shipments as domestic fuel.

In any case, I fail to see that the superior quality of the Crow coals is more than one factor in the question under discussion. If the lignites and the coals were both situated at the same distance from the market the briquetting scheme would have few defenders, but as a matter of fact one is at hand and the other is far away. Mr. McEvoy's argument against the shipment of anthracite west can quite properly be turned against his pleas for shipping Crow coal east. In each case it is a question of whether the total cost of the fuel plus its transport justifies its use, as against a different fuel costing more to produce but far less to transport.

Mr. McEvoy: Might I ask how much fixed carbon is precipitated from the volatile matter? We know, of course, that in coking coal a certain amount is precipitated, but it never reached a figure that we considered commercial.

Dr. Porter: The amount varies greatly with different coals, with the method of retorting and with the temperature of the distillation.

Mr. Dick: No one questions the high grade quality of the bituminous coals of the Crowsnest district. Mr. Lindsey has

shown that 2,118,000 tons of bituminous coal are imported by way of Port Arthur, and insofar as it is concerned, it is an economic question as to whether American or the Crowsnest coal should be used. We have to deal with economics, but is it fair to ask the railroads to do something you would not do yourself? Messrs. Lindsey and McEvoy are here holding a brief for the coal in the Crowsnest Pass, and it is unfortunate that there are not representatives present from Saskatchewan to express the views of the other side of the case The fact of the matter is that although bituminous coal is very suitable for the generation of power, it is not so acceptable for domestic purposes. During normal times bituminous coal can be bought in Toronto for $5 and anthracite is worth from $9 to 9.75. Does Mr. Lindsey himself use bituminous or anthracite?

Mr. LINDSEY: I am using both.

Mr. DICK: Undoubtedly most people will use anthracite, and the reason is that when firing up the domestic heater, if you use a high volatile coal and place it in the fire-box and turn the draught off, the volatile matter will start to distil and will not burn, but will flake up the flues thus wasting fuel. If you use an anthracite coal the volatile matter is low, and so when you shut off the draught there is no volatile matter to be distilled and the fire burns gradually and lasts for a long period. The otherwise excellent coal of the Crowsnest Pass district cannot be used in place of anthracite solely on account of this difference in its chemical constitution, although its calorific value is probably superior to the American coal we are now getting.

It is undoubtedly desirable to use Canadian coal in place of American as far as possible, but it is an economic question that is referable to the railways. The people of Saskatchewan have just as great a pride of country as those of British Columbia, and they say: "Let us devise a means to utilize our lignite coals so that they will replace imported anthracite, which has appreciated in price. Let us develop a mining industry in Saskatchewan." That is a quite laudable ambition; and if the proposed briquetting industry is established and proves an

economic success there is a considerable possibility of Saskatchewan becoming a big coal-producing field.

With regard to the heating value of carbonized coals and briquettes, I refer Mr. Lindsey to Bulletin 87 of the U.S. Bureau of Mines, which presents the results of actual tests made with these fuels in domestic heating boilers. In considering the available heat that is used in heating water for domestic purposes there are losses due to volatilization, fuel left in the ash and so on; and the tests show that in connection with the use of anthracite the loss of fuel in the ash is considerable, but with the carbonized briquettes the ash losses are very low, and that, moreover, for all practical purposes, the carbonized lignite briquettes made from North Dakota lignite compare favourably with anthracite coal.

Mr. Eli T. Connor, Scranton, Pa.: Respecting the 500,000 odd tons of anthracite coal that you have been importing into your northwestern provinces from the United States, I am inclined to the belief that the anthracite producers would not strongly object to your cutting off the demand at the line. Our problem in the anthracite region has been to spread the production so as to satisfy as many people as possible and during the past year we have had all kinds of difficulties to come anywhere near satisfying the people who were entitled to anthracite coal, among them the provinces referred to. I was very much interested in the discussion of by-product coking. I have recently been investigating for a client that very question of the feasibility from a commercial point of view of coking some of the high volatile coals we have in the United States that are low in fixed carbon, the object being first to save the by-products, and second, if possible, to produce a fuel that might be used for domestic purposes in competition with anthracite coal. Strange to say, the client who retained me is an anthracite producer. The experiments have not gone far enough to determine whether what have heretofore been designated as non-coking or high volatile coals can be successfully treated for the production of coke that is suitable for metallurgical uses, as well as the recovery of the by-products, but they seem to have

gone far enough to determine that point in the affirmative. If this process, which is the Roberts process, is found commercially successful it will widen very greatly the field where coals that heretofore have been designated as non-coking can be obtained. One of the questions to be considered is the distance to which fuels of a non-coking character may be transported. The Crowsnest coal is justly classed as among the highest grade coals produced on the continent. It seems to me that the practical question is: Can you produce Crowsnest coal to afford to send it any very great distance from the markets it has heretofore supplied ? This is a physical question—a mining problem. I had a little experience in that region, and while there are enormous deposits, the mining activities must be greatly enlarged in order to come anywhere near supplanting the 500,000 odd tons of anthracite you import from the States, and the two million odd tons of bituminous coal. I hope you may be able to do it.

Anthracite steam sizes as shipped to market will frequently analyse above 15% of ash. It varies with the size of the coal. In the course of preparation the slates and shales found in some coal beds break down into very small sizes. As to the domestic sizes, generally speaking, I don't think you will find up to 20%, as mentioned by a speaker preceding. I believe we can do better than that—the fact is, the average production of the anthracite region is decidedly better—but I am sorry to say there are producers shipping domestic coal that is not up to the standard of preparation that wise management requires. That criticism, however, cannot be applied to the larger producers. We have laboured under enormous difficulties during this war period, the demand for our production has been far beyond what we could supply, and as may be expected, there has been some carelessness in preparation that in ordinary times would not prevail. Another great reason has been the lack of labour. We are 25,000 men and boys short of normal force. We should have nearly 180,000 employees; we have only about 150,000. Therefore, when we have been able to produce 10,000,000 tons more in 1917 that the year before we don't feel that we should be censured too severely for letting a few pieces extra of slate or bone get into the market product.

Mr. R. A. Ross: We need to get the best out of the situation which we can and so render ourselves independent of importation from other countries. Why therefore should we hesitate to hesitate to do anything to make all our resources available, especially with such a trade balance against us? We are faced with a situation where we are dependent on the United States for a diminishing amount of anthracite, which their responsible advisers asked them years ago to restrict. They have not seen fit to take this action as yet, but in the immediate future I venture to say they will; but should they not do so, then the matter of price will restrict our imports and we must produce.

The first matter taken up by the Research Council upon its establishment was the fuel question. We found the situation presented a tremendous energy problem which rightly considered should include water-power as well. We made up our minds that as we were a commission, and might have been appointed for the purpose of shelving things, as some commissions are, we should make an attack on the most vulnerable salient in the whole front in order to ascertain how far we could be supported. We found that in the Northwest and in Saskatchewan particularly they had mines to the west of them which were shut down periodically and which were frequently short of cars and labour; and the inhabitants were importing anthracite coal and paying in Saskatchewan from ten to twelve dollars a ton in normal times, and to-day Heaven only knows what they are paying or whether they are getting it at all. We also found that the southern portion of the country was literally carpeted with unnumbered tons of lignite which was practically valueless for ordinary domestic purposes, and we made up our minds that this was a situation worthy of examination; but presented no recommendations to the Government until we had made a thorough study extending over six months. During this time we had the most hearty co-operation of the Government departments interested, Mr. Dick, of the Commission of Conservation, and Mr. Haanel, of the Department of Mines, being of the greatest assistance. Finally, we decided that we could safely recommend the production of carbonized lignite briquettes.

Now it has been stated here that this is a luxury. Electric lights are also a luxury, for you can use coal oil which is cheaper. Mr. McEvoy's idea on similar lines is that we should not manufacture anything, as it costs more than the raw product. On the same basis we should eat raw turnips instead of cooking them. People have a taste and are willing to pay for it, and if we can produce something which can give the people of that country a Canadian product of the same value as imported anthracite and at the same price we are at least keeping that amount of money in the country.

That being the situation we felt that the demands would have to be supplied in a different way, as these had not been met hitherto by Canadian interests. Our mines have been in existence for twenty years, and their product has been spoken of here as superior to the coal being supplied from elsewhere. If in that time this market had not been secured we felt we were entitled to go into the whole question and try to supply to that district what the Canadian mines which had been at it for twenty years had been unable to do, and I consider we were perfectly entitled to go into the question from that point of view.

We can disregard the diversity of opinion expressed here as to fixed carbon and all that, for we have tests made on briquettes of Saskatchewan and North Dakota carbonized lignite which have been turned out not in a laboratory way but in carload lots, which have been burned by the United States' Government departments and found to be superior to the best anthracite, not because they have more B.T.U.'s in them, for they have slightly less, but because they are uniform in texture and burn in such a way that this artificial hard coal is declared by those authorities to be better for domestic uses, so that does away with all question of chemistry and gets down to commercial facts.

Mr. LINDSEY: Have you the figures ?

Mr. ROSS: Not with me, but I can substantiate what I say and shall be glad to. (See Bulletin No. 89, U.S.A. Department of the Interior, Bureau of Mines.) The tests were made on the

lignites in coal stoves and also furnaces, and when you have tests of that kind before you and find that these lignites have been successfully carbonized and briquetted, but that this has not been carried on in one plant as the materials have been taken from one plant to another for different processes, the future problem then becomes one of the production of a commercial article in one plant and selling it as a commercial article in the open market. This being the situation, we said to the Government: If you will give us a certain amount of money to put up this plant, remove the matter out of politics, and put it into the hands of a commission or company made up of some of the biggest men of the Northwest and one or two technical men from the department who will handle it as a commercial proposition and sell the product in the open market, then we will come to you in a year and give you the results of a commercial demonstration of what has been done. The results of our studies convinced us that the cost at the briquetting plant would not exceed $7.00 a ton, and this with a small plant turning out not over 100 tons a day, the capital cost of which would not exceed $400,000. If that is successful you have not only a fuel equal to anthracite, but a demonstration that will be of immense benefit to the coal men of the West. If we can do it with the worst coal in the world these men can profit by it and keep their mines going 365 days in the year, briquetting the excess and keeping their miners employed during the summer. And when that demonstration is finished others, if they so desire, may adopt the same course in treating the better coals of Alberta; and this plant will be available for the purpose of standardizing the method of operation for any other class of coal in the Northwest.

Dr. F. D. Adams: With regard to the question as to whether two tons of the Souris lignite will make one ton of the carbonized lignite briquettes, I may say that we know that such is the case, because it has been demonstrated first by Mr. Babcock and then by Mr. Darling, whose work on this subject has already been published. The briquettes in question have been analysed repeatedly, and shown to have a fuel value practically equal to American anthracite.

It is rather reassuring to those who, after a very thorough study of the subject in all its aspects, have put forward this method of utilizing the great fuel reserves of the Eastern Plains which are now lying practically neglected, in a region where fuel is so scarce, to note that the expressions of disapproval have come only from gentlemen whose interests lie in the coal fields of the Rocky Mountains. These gentlemen point out that the coal from the far western region can be brought into Winnipeg, and could quite adequately supply this and the surrounding market. But no new situation so far as these western coals are concerned is being created by the proposal to make use of the Saskatchewan lignites. For twenty years or more the conditions have been as they now are, and Winnipeg has been drawing and still is drawing a large part of its coal supply and practically all its anthracite from the United States. If the Government or someone else would pay the carrying charges for the transportation of the Rocky Mountain coal to Winnipeg, this fuel could be delivered there at a profit to the operators—under like conditions it could be brought to Montreal. This solution of the problem, however, is not one which is either desirable or feasible, and hence it seems clear that we should at once bend our efforts in the public interest to making available for the use of the people of eastern Saskatchewan and Manitoba the deposits of fossil fuel which lie practically beneath their feet.

I would also point out that a certain confusion is introduced into the discussion of the subject when reference is made to the composition and fuel value of "western coals." It must be remembered that the very high grade bituminous coals which have been mentioned lie in the heart of the Rocky Mountains, and are hence most remote from the markets in Winnipeg and the east. The Drumheller coal which is nearer to these markets and which is now being so extensively mined is classed in the Alberta Government reports as a lignite.

Mr. LINDSEY: One would hardly expect that method of attack. The Crowsnest Pass coal needs nobody to hold a brief for it. On its merits it holds the highest place, and any question of carrying it east or west is outside of that. I deprecate seriously

the introduction of that spirit which would seem to impute the honesty of men's motives when they are endeavouring to deal with a scientific problem.

I am glad Mr. Ross spoke. He tells us he came to this task with the knowledge that the whole West was carpeted with lignite, and if the whole West is, as Mr. Ross says, carpeted with lignite, and people want to keep warm, let them use lignite in their stoves. Don't ask the Government to convert it to something else which by the very statement of the case appears to be a luxury. I cannot deal with men whose case is based on shifting figures. I came here to deal with the case on the figures presented by Mr. Dick, and I repeat that they do not bear out the position the Government is asked to take in establishing this plant. It is easy to talk in generalities and for Dr. Porter to say I have forgotten my chemistry. I have forgotten nothing of the kind. I have made more coke in a month than Dr. Porter ever saw in a lifetime, and I know from practical experience what can be, and is, done. I put this case to you on the figures that have been presented here, and not on those that are not. And I say if you take the figures as presented, if you take the very mines we are asked to consider, for example, the Estevan, with a fuel having 28% fixed carbon and you convert two tons of it, you get 56% fixed carbon, and as such you are not going to get the other fixed carbon from the volatiles to bring that up to 86%.

Mr. Ross tell us that one of the great virtues of this new briquetted lignite is that it burns so excellently because of the equality of ash. Did he ever stop to think what the ash content of it was in relation to the ash content of an anthracite? I am not speaking of badly mined anthracite with rock unpicked. It runs about 8% in normal clean anthracite, and yet this briquetted coal taken from the Shand mines with a fixed carbon content of 61% will have an ash content of 20%—that is, one-fifth of it won't burn at all. I cannot meet a case built up on figures that are not before us. If it is true that these coals have been briquetted and the B.T.U.'s are different from what Mr. Dick has put forward, then that is a subject for another discus-

sion at another time, when the new figures in their proper relations are presented; but we have to deal with the facts as we find them. Mr. Dick, in his statements, points out that the American Bureau of Mines in their experiments have produced a briquette of carbonized lignite, the fixed carbon content of which lies between 72% and 82%. If he has something of that kind made from Saskatchewan lignite it is a very different carbonized briquette from that to which all the analyses that he presents have reference.

I repeat, without the slightest fear of contradiction, that no case has been made out on the evidence submitted to show that the anthracite fuel from the United States can be met in competition with a fuel converted from these lignites, or that this product will bear the slightest comparison with American anthracite in calorific value or cost. But I qualify that by this statement, that if there is evidence of another set of figures, if there is something else that we don't know about in detail and relation, I want to have an opportunity of considering those figures and their value. If there is a higher fixed carbon content in a ton of briquettes than has been shown from two tons of lignite, I want to know whether more than two tons of lignite went into it or not, and then we can discuss the result. But at present I repeat you cannot make out of the lignites anything that will compare with the anthracite coal of the United States, nor out of two tons of lignite as valuable a coal in fixed carbon content or calorific as Crowsnest coal.

Dr. PORTER: Mr. Lindsey says he has made more coke than I have ever seen, and he has not forgotten his chemistry. If so, it is most astonishing that he should remain so absolutely ignorant of the first principles of coke manufacture. That is a very plain statement, but it is true. Mr. Lindsey should know perfectly well that the fixed carbon in coal is not the only source of the fixed carbon in coke. It is true that his old ovens at Fernie were of a very wasteful type, but with any decent modern type of oven it is perfectly possible and commercially quite practicable to turn out more fixed carbon in coke than there was fixed carbon in the coal.

Mr. Lindsey: How much more ?

Dr. Porter: It depends on the coal, and on the ovens, and also very much on the man who runs the plant.

Mr. Lindsey: You won't answer that question.

Dr. Porter: Of course not; I don't know the coal well enough and I do not try to keep exact figures of such a complicated sort in my head, but it will be easy to get trustworthy data if you really want it.

Mr. Edgar Stansfield: Dr. Porter is quite right in stating that a certain amount of volatile matter does decompose when coal is coked, thus raising the percentage of fixed carbon; the amount decomposed depends entirely on the method of coking.

The methods of coking lignite can be varied indefinitely; in a paper by Stansfield and Gilmore, presented to the Royal Society of Canada, last year, a large number of tests were given showing calorific values of the carbonized residue ranging up to nearly 14,000 B.Th.U. per lb. Some of the methods employed were not commercial; others might be. Previous speakers have omitted consideration of the binder which would be necessary. The addition of say ten per cent of a binder having a heating value of 18,000 B.Th.U. per lb. would materially change the analysis and heat value of the resulting briquette. It is impossible to discuss intelligently any commercial project for the carbonization and briquetting of lignite without details of the proposed methods.

One speaker stated that anthracite contained about 8% of ash. A number of samples we analysed in Ottawa, in 1916, averaged somewhat over 10% ash; similar samples this season averaged about 15%; I trust that next season we will not find 20%.

Mr. O. E. S. Whiteside: Coming as I do from the Crowsnest Pass coal district, the suspicion may perhaps be entertained that I may hold a brief for Crowsnest coal, and it may be that I am slightly prejudiced without knowing it, although I hope I am broad enough to consider this subject in a fair and impartial manner.

In the east the majority of the members of the Institute are, of course, metal miners and metallurgists, and a correspondingly large number of papers are consequently on metal mining and metallurgical subjects—hence I am agreeably surprised that so much time should be devoted at this meeting to the consideration of questions relating to fuel.

I do not know whether Mr. Ross or any of the other members of the Advisory Council have studied possibilities, other than the briquetting of lignites for the replacement of a quarter of a million tons of anthracite that is being consumed annually in Winnipeg, or the other quarter of a million used west of there; but I would like to suggest for general consideration the possibility of coke—manufactured in by-product ovens or gas plants—using Crowsnest Pass coal. We know we can make coke, not only in the laboratory, but commercially. The people of Winnipeg are not yet educated to burning coke instead of anthracite, but there are places where they like it better and use it exclusively.

Referring to the remarks of Mr. Johnson, I am surprised to hear a mining engineer admit that he could not burn 'the miserable coals of the Crowsnest Pass District.' The people located there have come from all over the world and consequently are experienced in the use of many kinds of fuel, but I venture to assert that not 10% of them know how to burn anthracite, and if they had to burn it they might consider it 'miserable stuff.'

Many people are able to burn only one kind of coal, and it requires education, time, and opportunity to induce a change. Even although their particular variety costs more per heat unit they will continue to use the expensive article. Under the conditions obtaining in Western Canada it is not, in my opinion, as necessary or advisable to change the grade of coal as it is that the furnace and the user should be adapted to the coal.

I am willing to admit at once that there has been a serious shortage, not only of anthracite, but of every other kind of coal, at various points not only in Eastern Canada, but throughout the eastern part of the United States; but I would like to ask the

question—has there ever yet been a real shortage of fuel in Winnipeg or west of there? True, there have been occasions when people suddenly were confronted with 52° below zero temperatures without coal in their cellars and everybody could not be supplied at an hour's notice by the agents—and they at times have not carried over large stocks—but the Western mines should not be held responsible under any such circumstances.

Answering my own question—and this answer will have special reference to the remarks of Mr. Connor in regard to the capacity of Western Canadian mines—I would say positively, there has not, in recent years, been a real shortage of coal in Winnipeg or westward, due to the inability of Western mines to ship. Some people out there just now are getting desperately afraid that the American product will be transferred farther east this year, and it is only a few weeks since the representatives of the Committee for National Defence for the Dominion were sent all the way to Alberta to interview the operators of that Province with regard to the possibility of getting Alberta coal in as far east as Winnipeg, in case such a contingency arose. Although these men were intimately connected, not only with transportation, but many other lines of business throughout Alberta and the Western Provinces, yet they (although they may have shown some surprise not altogether real), were actually surprised to some extent to find out from the operators, after they had been told the number of tons of bituminous and anthracite coal that had been imported into Winnipeg and the West, that the Alberta mine owners were not only able but mighty anxious to supply every pound of coal necessary for Winnipeg and west; and, in addition, were prepared to take care of the requirements as far east as Fort William. I have forgotten the exact number of tons they said we imported, but at any rate, I think it amounted to about one million and a half tons of domestic and slightly over a million tons of bituminous, and the tonnage which the operators were prepared to supply totalled up to an increase of four million and a quarter tons over and above what they shipped last year—a very considerable amount, and more than enough to meet the requirements of Fort William and west of it. This total increase was conditional on

getting some more men, but the operators felt satisfied that the requisite labour could be secured if they were assured the tonnage. It was also conditional on steady work, absence of strikes, and ample transportation.

As a check on these figures I might say that the Chief Inspector of Mines for the Province of Alberta, without asking for information from the operators, and some time prior to the end of 1917, estimated that if these mines could be kept operating steadily throughout 1918 they could get out 3,041,511 tons more than they shipped last year.

Notwithstanding strikes of two and a half months during 1917, Alberta produced a quarter million tons more than during the previous year, and the problem now to be solved there seems to be one of transportation, and the solution of this problem should not be impossible. Mr. Lindsey pointed out that coal from the Lakes was hauled as ballast west, it being hauled in cars which had carried wheat eastbound; and it is, of course, under present circumstances, to the advantage of the railways to give a cheaper rate that way. The average rate at present from the Rocky Mountains to Winnipeg is about $4.40 a ton, and from Winnipeg to Fort William, a comparatively short distance, $3.80 a ton more. The freight from Fort William to Winnipeg is, I believe, about $2.50 a ton at present.

When these figures were discussed at the Calgary meeting, there were a few railway men present, and the coal operators were interested to know whether the railways could undertake to guarantee the necessary transportation; they were not quite so positive just what could be done or how much increase would be required, but they intimated that they were going to report to headquarters immediately and that certainly something would be done, and that as much assistance as possible would be given the industry.

Personally, I feel that if the American coal is shut off (or if their previous allowance is transferred farther east) from the city of Winnipeg, that they will have no difficulty from any cause whatsoever in being supplied their total requirements from Western Canadian sources.

In the district of Drumheller they made last year an output of 660,974 tons, and the operators from this district assured this committee they could produce a further tonnage of 1,800,000 tons this year. I think if there is any truth in this statement whatsoever it indicates that there is a considerably greater over-development of coal mines in the West than there ever was of coal shortage Winnipeg and west.

Even without any change in transportation facilities as compared with last year, but simply by having the men work steadily throughout the year and getting the consumers to order a fair portion of their requirements during the summer months, these mines should be able to provide for the requirements as far east as Winnipeg.

The people of Winnipeg are now interesting themselves in this problem. The Chairman of the Manitoba Branch of the Canadian Society of Civil Engineers, I believe, has appointed a committee to help educate the people with regard to the use of Western coals in case the necessity arises, and replying to some of his queries I not only agreed with him in his opinion that they could manage very well with this fuel, but told him something which maybe the people of Ontario and the eastern part of the United States might be glad to know, viz., that Winnipeg could not only be assured of the necessary coal supply, if ordered early and transportation was afforded, but that under the present circumstances they ought to be willing to do without any American coal during the lifetime of this war, at any rate, if by so doing better provision would be made for the people farther east.

Dr. J. G. Davidson: In this discussion no reference has been made to the value of the by-products from the proposed treatment of Saskatchewan lignites. One of these by-products is sulphate of ammonia, which is an exceedingly valuable fertilizer. Already in certain sections of the prairie country there are indications that the soil needs replenishing, and the day is not far distant when the demand for fertilizers to enrich the wheat-growing areas will be urgent and widespread. Hence this phase of the question must not be disregarded or forgotten.

Mr. LINDSEY (*communication to the Secretary*): Now that those who participated in the discussion of Mr. W. J. Dick's paper, read at the last annual meeting, entitled "Waste of Coal in Canada," have had the opportunity to eliminate many of the arguments there used and to add to and to vary them (a process which I think you are wrong in permitting), there seems to me to be one point to deal with. That is the suggestion by one debater that the carbon content of "anthracite" made from Western lignites is increased from carbon contained in the volatile matter.

There is only one person that I know of in America who has practically dealt with the question of carbonizing Western lignites. That is E. J. Babcock, North Dakota University, author of "Economic Methods of Utilising Lignites." I recently addressed a letter to Professor Babcock asking him how much the residue was increased as to carbon content by any re-deposition of carbon from the volatile constituent of the coal, and his answer was—to no extent whatever.

Here is what he says:

> In your letter you ask also as to whether we derive more fixed carbon from one ton of coke than would be derived from the original fixed carbon in the lignite and, if so, where it comes from. I suppose you mean instead of coke, the lignite residue after carbonization.
>
> Generally speaking we do not derive any more fixed carbon in the residue than the proportion that exists in the original lignite. In some coals, however, and under certain conditions of carbonizing a little of the volatile lignite tars are broken up so as to leave a very small amount of pitch residue, but usually this is not of sufficient quantity to be worth considering commercially.

A PROPOSAL FOR THE COMPLETE ELECTRIFICATION OF THE INDUSTRIES AND TRANSPORTATION OF CAPE BRETON ISLAND

By VINCENT MCFADDEN, Chief Electrician, Dominion Coal Company, Glace Bay

(Annual Meeting, Mining Society of Nova Scotia, May, 1918)

There never was a time in the history of this country when it was so necessary that the great wealth of natural resources which it possesses should receive attention and be developed to the fullest extent as at the present day; and, if we are to judge by the opinion of leading citizens, by the attitude of our civic and municipal governing bodies, and by the disposition shown on all sides to favour and encourage and, if need be, liberally to subsidize the establishment of various industries, we can see that our people are indeed beginning to realize this fact and are prepared to give every consideration to any proposition whereby there can be brought about a more complete development of the great advantages with which Nature has favoured our island.

With a view, then, of creating a discussion on this subject, I venture to outline briefly for your consideration such a proposition. For the past number of years the people of this part of the country, especially of the city of Sydney, have centred their attention on the establishment of a shipbuilding plant on the shores of Sydney Harbour, which, it is rightly contended, possesses advantages unsurpassed in Canada for the creation of such an industry.

Our iron and steel plant, with its large production of the required material, and our vast coal areas furnishing an unlimited supply of fuel, are pointed to as advantages to induce shipbuilding and other manufacturing plants, for which coal, iron, and steel are essentials, to locate here.

But the question is, are these sufficient? Are we now prepared to offer our entire wealth of natural resources that are equally essential to the success of manufacturing? To my

mind the answer is that we are not so prepared, and the first step necessary to make that preparation is the development of the natural resources which, in the past, we have permitted to remain practically in a dormant state.

Coal, iron, and steel we have in abundance, and they can be supplied cheaper, probably, than in any other part of Canada. But if we were in a position to offer in conjunction with these the great possibilities of our farm lands and fishing grounds, we would be offering to the establishment of various industrial plants inducements that would defy competition. In offering these we would not only be reducing the cost of living, and thereby giving an advantage to labour, but we would be furnishing the raw material in many lines of manufacture, the finished product of which we are now obliged to import. Instances could be multiplied, but one will suffice for illustration, and that is the manufacture of leather, the raw material for which we could supply if we had large stock-raising farms.

There is within a short distance of our shore abundance of fish, and all that is required to stock our markets with the fish of our coastwaters is the trained fisherman, the necessary equipment of the modern type, and the efficient means of transportation to ensure prompt delivery.

We have in Cape Breton thousands of acres of uncultivated lands which, in point of general productiveness, are equal to the best in Canada. If these fertile acres that are going to waste were cultivated to their full capacity of production, Cape Breton could easily supply its own market and have a fair surplus for export.

On the Island of Cape Breton there is, and has been for some time past, approximately $16,000,000 per year paid for the labour of manufacturing iron and steel and the mining of coal. This is money that is coming in from other parts of the country, and of this amount fifty per cent is sent back again for our farm produce. If this amount of $8,000,000 could be kept here in circulation, that in itself would be the means of making our island one of the wealthiest parts of Canada, but

to make farming a success in this island, to place it on such a paying basis as to induce trained and experienced farmers to take up our vacant lands and apply the modern methods of scientific farming, the one great problem to be faced and solved is the question of transportation.

Under present conditions, with practically one line of railroad running through the island, and that one only about one-quarter equipped in rolling stock and carriage equipment, with highways that are almost impassable, it is impossible for the farmer to market his produce, and consequently farming is not paying to-day in Cape Breton.

Where then are we to find a solution of this great problem ? The answer is that it is to be found in the establishment of electric power plants with transmission lines extending throughout the island, bringing power that can be utilized to great advantage in every class of industry, within easy reach of the farmer as well as the manufacturer, and affording both the most complete and efficient means of transportation. In the great Province of Ontario attention has been directed to this question for the past number of years with excellent results.

Many may be of the opinion that the Province of Ontario has one advantage which we have not in this respect, and that is water-power. They may argue that it is out of the question for us, without water-power, to undertake to generate electricity as cheaply as it can be generated in Ontario, with its immense water-powers. This, however, is a mistaken idea, as it can be easily demonstrated that power can be generated from our coal and transmitted throughout the different parts of the island at a cheaper rate than from any of the great water-power plants of Ontario.

To illustrate this, I may say the capital necessary to install a water-power plant of, say, 20,000 kilowatts will be approximately $150 per kilowatt, or $3,000,000. Should it be necessary to build a big dam to give large storage of water, it may cost from $200 to $250 per K.W. But taking the cost at $3,000,000, which it would be under favourable conditions, fixed charges including

running expenses, which would be chargeable to the cost of power, would be about 9 per cent, or $270,000 per year. A 20,000 K.W. plant and carrying 40 per cent load factor for 365 days would generate 70,080,000 K.W. hrs., and by dividing the $270,000 by the K.W. hrs. generated would give a cost of .388 cents per K.W. hr.

If we compare this with a like size plant established at one of our coal mines in Cape Breton we find that the capital expenditure necessary to have power generated will not be as great, that the extra revenue derived from such a plant will be larger than from a water-power plant, that the electric current may be regarded as one of the products and the power sold profitably at a lower rate than is possible in Ontario.

This can be accomplished by placing the same size plant at one of our coal mines, and by installing in connection with the plant a gas-producer of the by-product recovery type and using gas engines or by burning the gas under steam boilers with high-speed turbines to drive the electric generators. The approximate cost to install a plant of this type with a capacity of 20,000 K.W. with boilers, engines, electric generators, switchboards, building, and all necessary auxiliaries would be about $75.00 per K.W., and the gas-producer costing an additional $25.00 per K.W. would make a total of $105 per K.W., or a grand total of $2,100,000. By calculating the fixed charges, including labour and fuel, at twenty per cent of the capital expenditure, they will amount to $420,000 per year. Then taking the same amount of current generated as in the estimate of the hydro-electric plant, 70,080,000 K.W. hrs. will make a gross cost of .6 cents. But there is a credit due the plant from the by-products, from the sulphate ammonium alone, which finds a ready and constantly growing market amongst agriculturists and farmers as one of the best known fertilizers and commands prices of upwards of $55 to $60 per ton. But the yield of sulphate possible to be obtained is dependent primarily upon the nitrogen contents of the fuel. This, in the case of our average coal, should yield at least 85 lb. per ton of coal gasified, and taking the coal consumed per K.W. hr. at 3 lb., would amount

to approximately 100,000 tons. 85 lb. of sulphate per ton then would give 4,250 tons, and sold at $55 per ton will give $233,750. This amount deducted from the cost of running the plant will give the cost of current at .263 per K.W. hr. as compared with .385 cents for the current generated by the water-power plant. This saving in itself will amount to nearly 4 per cent of the capital expenditure, and if inferior grades of coal are used the saving will be considerably greater.

But when we compare general conditions in Ontario with those we have here, we find there exists there one advantage for the development of large power plants, which we have not, but which, in my opinion, we should have no difficulty in acquiring. There are in Ontario a large number of towns and cities, all having many and important manufacturing concerns that are extensive purchasers of power, whereas in Cape Breton at present there is no great amount of power used outside of the coal and steel industries, and the two corporations have plants of considerable size to supply their own requirements. But as soon as cheap power is available, why not create a market for it ? There should be little difficulty in doing this. The Intercolonial Railway is the largest consumer of power outside of the corporations already mentioned, and as it is a Government-owned road there should be no difficulty in having it converted into an electrically operated road, and the cost of operating would be considerably less then under the present system. The line as at present running from Sydney to Point Tupper could be maintained as a main trunk line, and from it there could be built branch lines carrying current for transportation purposes by trolly cars along the several highways, as well as also power into the farming sections to be used as a substitute for man-power; and the transmission lines branching off would run to any part of the island where it might be required for manufacturing purposes.

For example, we could have one line branching off at Little Bras d'Or running through Boularderie; a second line branching off at Grand Narrows, running easterly through that district and along the shores of East Bay, and continuing on through Sydney

Forks, connecting with the main line at Sydney River; another branch starting from the main line at, say, Orangedale, and running westerly through Whycocomagh, Port Hood, Mabou, and Inverness, and on through the beautiful valley of Margaree, one of the richest agricultural districts in Canada; and a branch from Whycocomagh running northeasterly would reach Baddeck and pass through the fertile valley of Middle River; and another branch starting from the main line at Point Tupper would run through St. Peters, Grand River, and Loch Lomond, reaching the Mira's, thence into Sydney.

These branch lines could be built to serve the available traffic at a cost of less than 25 per cent of what it would cost to build the same line for steam power operation.

The cost of the overhead electrical construction, necessary transformers, and switch equipment for the converting of the main line should not exceed $3,550 per mile, and the present locomotives could be replaced by electric locomotives to do the same work at a cost of approximately $30,000 a unit. This would not be a great expenditure compared with the small cost in connection with the running expense, and the benefit this part of the country would derive from it.

A daily passenger and freight service could be maintained at a minimum cost. With this system in operation every section of our island would be opened up, and we would then be in a much better position to offer the necessary inducements to trained and scientific farmers to undertake the cultivation of our vacant lands. In the markets of our cities and towns and industrial centres we would have an unlimited supply of the products of our own lands, and we would no longer be importers of farm produce, but exporters. We should have the large amount of money that is now going out to other places each month, for farm produce, remaining in circulation on our island. We should also be in a much better position to offer inducements to shipbuilding and manufacturing concerns to locate here. The cheap power alone would almost be sufficient inducement to them to do so. Thus a manufacturing plant of 1,000 horse-power running 300 days in the year could in such circumstances

purchase its power here at one cent per horse-power cheaper than in any other seaport in Canada. This saving in the cost of power would pay a great portion of the fixed charges on the capital expenditure of such a concern.

We would also be in a position whereby it would not require a great expenditure to tunnel the Strait of Canso so that the electric passenger and freight trains could run through to the other parts of the Province without the loss of time, the inconvenience, and expense of the present unsatisfactory method of transferring passenger and freight traffic at that point. There is no reason why a similar power plant could not be established at one of the coal mines of Pictou County, and another at the coal mines in Cumberland County, with connecting transmission lines, whereby power could be supplied to the whole of the Intercolonial Railway system of Nova Scotia, and as well supply current for lighting and power to all parts of the Province.

Discussion

Mr. F. L. Collins: There are in North and South America to-day roughly 358,000 miles of railroads on which steam locomotives are operated, as compared with about 217,000 miles in Europe, and 117,000 miles in Asia, Africa, and Australia. The electrified divisions of the steam railroads in the United States which may properly be classed as trunk line electrifications aggregate approximately 2,500 miles, or more than double the steam road conversions in Europe. The first railway company in the United States to adopt electrification was the Baltimore and Ohio. This was in the year 1895. This was followed by several other railroad electrifications, including that of the New York City terminals of the New York Central and the New Haven Railway in 1900. Up to this time electrification had been adopted mainly to obviate the smoke nuisance and to facilitate the handling of heavy suburban passenger traffic. Economic reasons were advanced as secondary considerations, and it was

difficult to secure sufficient operating data to bear out claims of more economical operation for electrical equipment. In 1913, however, the Butte, Anaconda and Pacific Railway purchased electrical equipment to supplant the heavy steam locomotives used for hauling ore trains between Butte and Anaconda with the definite intention of reducing operating expenses over and above reasonable charges against the increased investment. The satisfactory results achieved in this instance largely influenced the decision of the directors of the Chicago, Milwaukee and St. Paul Railway to electrify its 440-mile section of mountain railroad. Later, in January, 1917, the Chicago, Milwaukee and St. Paul undertook the electrification of 250 miles more of its steam road, making a total of 690 miles, which is practically equal to the distance from Sydney to Levis, or three-quarters the distance from Sydney to Montreal or Boston. The portions of these two railroad systems which have been electrified are probably subjected to the most severe operative conditions that exist in railroading anywhere in the country. Hence the results are all the more interesting. For example, in the case of the electrification of the railway in the Rocky Mountains above referred to, electric locomotives now haul ten and twelve steel cars at a speed of twenty to thirty miles per hour over a 2% grade. The tonnage on freight trains has been increased from 1,700 tons to 2,500 and 3,000 tons; and this tonnage is handled at a speed of fifteen to sixteen miles per hour on maximum grades. The steam locomotives could only average eight to ten miles per hour.

Due to the long, heavy grades, regenerative braking is a feature that has proved most successful and most economical. Heavy transcontinental passenger trains are moved down maximum grades at a uniform speed by this method of braking; and freight trains of maximum tonnage are handled in the same manner without the use of air-brakes, unless the train is stopped. It may fairly be stated that the use of electric locomotives, so far as easy and uniform operation is concerned, has practically eliminated the grades of the Continental Divides. Regenerative braking has shown great saving in brake-shoes and wheels. The delays to trains for the purpose of cooling brake-shoes and wheels

is also an economy that has been found to be far-reaching in handling of both passenger and freight trains.

An interesting comparison of the operation of steam and electric locomotives under severe weather conditions is afforded by the following actual happenings: Two freight trains, composed of three steam locomotives and seventy-five cars, were standing on the main track east of Three Forks, Montana, with the engines dead on account of the bitter cold, the temperature being 40° below zero, and passenger trains were due in both directions. The superintendent was naturally anxious to clear the main line, but had no steam engines available. An electric freight locomotive was standing on the side track at Three Forks. At this time only the yard and about nine miles of trolley had been energized. The electric locomotive moved out on the main line, coupled up the two trains, and without the slightest difficulty pulled into the siding, cleared the main line, and allowed the passenger trains to go through without delay.

The electric locomotive, while handling much greater freight tonnage, gets fewer drawbars, because the pull is uniform and easily controlled, and it is practically impossible for drawbars to be pulled out, except as a result of extreme carelessness.

The present saving due to regenerative braking made possible by the electric locomotive in use on the Chicago, Milwaukee and St. Paul Railway has been from 7% to 25% of the actual power delivered to the motors.

Some of the general results obtained by electrification have been: (1) a 50% increase in the available capacity of existing tracks; (2) under all conditions of service there is an increase in reliability and capacity; (3) speeding up of train schedules to the extent, under average conditions, of 25%; (4) in extremely cold weather the steam locomotive practically becomes useless, while the electric locomotive is most effective, and able to handle maximum loads; (5) the steam locomotive requires about 6 lb. of coal per H.P. developed, whereas the electric locomotive only requires 2 lb. of coal per H.P. developed, with

a consequent conservation of two-thirds of fuel requirements; (6) it is estimated that 10% of ton mileage movement in the United States is required for coal used for railway locomotives. This would be largely reduced by electrification.

MR. VINCENT MCFADDEN: At the time I prepared the paper my principal object was not to demonstrate the possible saving of fuel only, but to point out that there are sections of the Island of Cape Breton containing farm lands equal to any in Canada, which are in large part uninhabited because the cost of sending produce to market is equal to the cost of producing it. Up to a few years ago the electric locomotive was in an experimental stage, but that stage has now been passed and it has been proved that electric locomotives can be operated at a lower cost than steam.

MR. F. E. LUCAS: I believe that the future of the coal industry of Cape Breton is largely bound up with the questions of the gasification and recovery of the by-products of coal.

MR. F. W. GRAY: Mr. McFadden's paper advocating the installation of large power plants near the pit mouth for the generation of electric current on a large scale, combined with recovery of the by-products of coal, has received significant confirmation in the report of the Haldane Commission in Great Britain, which, as will be recollected, recently reported in favour of the supersession of some 600 power plants in Great Britain by 16 super-power stations for the generation of electric current from coal combined with recovery of the by-products.

Nova Scotia resembles Great Britain in that it possesses no important water-powers available for the development of hydro-electric energy. Canada, considered as a whole, is very fortunately situated in regard to water-powers, and in a paper recently read before the Canadian Society of Civil Engineers by Mr. J. B. Challies, the Superintendent of the Dominion Water Power Branch of the Department of the Interior, it was stated that out of a total of 18,803,000 H.P. available from water-power sources only 1,735,598 H.P. has been developed, or less than 10% of the available water-powers. The available water-power of Nova Scotia is given as 100,000 H.P., of which 21,412

H.P. has been developed. It will be seen, therefore, that Nova Scotia cannot look for much further help from water-powers, and must depend upon its large deposits of bituminous coal as the source of its future supply.

Mr. McFadden's paper was brought to the attention of Mr. John Murphy, the Electrical Engineer of the Department of Railways and Canals, who writes as follows:

> The paper has been read with much interest, and I am prompted to suggest for study or consideration the feasibility of the idea of building trackless trolley lines throughout those portions of Cape Breton which it is proposed to electrify, which may as yet not be ready for railways on account of the high cost of building and maintenance of railroads. The whole world is daily becoming more and more appreciative of the value of good roads. No township should be so unimportant or poor as to be without good roads. For sparsely settled districts it seems to me that (a) good roads, (b) the automobile, and (c) the trackless trolley, in the order mentioned, will arrive in advance of standard electric railways.

Mr. Murphy has also recently read before the Canadian Society of Civil Engineers a paper on "Railway Electrification," and has been good enough to consent that certain portions of this paper should be extracted as bearing on our discussion of Mr. McFadden's paper. Mr. Murphy points out that to eliminate the need of coal at a considerable distance from the mine is a greater measure of relief and of true conservation than increasing mine production and thereby incidentally adding more load to the already overburdened railways. The reduction of coal consumption automatically relieves or releases men and apparatus all along the route from the mine to the consumer. It also relieves the route itself from some of its congestion.

Mr. Murphy quotes the President of the American Institute of Electrical Engineers, Mr. E. W. Rice, as stating that 150,000,000 tons of coal, or nearly 25% of all the coal mined in the United States, was consumed in steam locomotives last year, and Mr. Rice enlarged upon this statement as follows:

> It is really terrifying to realize that 25 per cent of the amount of coal which we are digging from the earth is burned to operate our steam railroads —and burned under such inefficient conditions that an average of at least 6 pounds of coal is required per horse-power hour of work performed. The same amount of coal burned in a modern central power station would produce an equivalent of three times that amount of power in the motors of an electric locomotive, even including all the losses of generation and transmission from the power station to the locomotive.

Mr. Murphy states that in Canada about 9,000,000 tons, or 30% of the total Canadian coal consumption, was consumed in steam locomotives last year.

Mr. Murphy gives some striking examples of actual experience on electrified railways. The Butte, Anaconda & Pacific Railroad by electrification increased its ton mileage 35%, and at the same time decreased the number of trains and their incidental expenses 25%. The time per trip was decreased 27%, and the saving on the first year's operation, after electrification, amounted to 20% of the total cost of electrification. On the Norfolk and Western Railway 12 electric locomotives have replaced 33 Mallets of the most modern and powerful type. The tonnage has been increased 50%. The salvage value of the released steam engines was 45% of the cost of electrification. Electrification obviated the necessity for double tracking.

The 440 route miles of the Chicago, Milwaukee & St. Paul Railway which have been electrified will soon be augmented by 450 miles more. Some of the results secured are as follows: The cruising radius of each electric locomotive is twice that of one steam engine. Sub-divisional points where freight crews and steam locomotives were formerly changed have been abolished. The passenger crews' runs are now 220 miles instead of 110 miles. On a mileage basis alone, operating costs of the electrics are less than half the steam-engine costs. Freight traffic increased 40% shortly after electrification. Double tracking would have been necessary to handle such increased business under steam operation. An average increase of 22% in freight tonnage per train has taken place.

The three railways mentioned operate on mountain sections, and it is stated that the behaviour of electric locomotives on steep grades is in every way superior to the behaviour of steam locomotives. Delays from cold weather are much less in the case of electric locomotives and in one three-month period on the Chicago, Milwaukee & St. Paul Railway cold weather delayed steam trains 445 minutes, whereas no delay to electric locomotives took place from cold-weather conditions.

The vice-president of the last-mentioned railway is reported as stating that "Electrification has made us forget that there is a continental divide."

Mr. Murphy concludes by stating that:

> While the present fuel-shortage questions have made us look to railway electrification for relief, I feel such a project on a large scale can only follow or go hand in hand with power plant development and co-operative operation of power plants. The erection of a number of plants at different points—large water plants and auxiliary steam plant so situated and interconnected that a failure at one plant or the connections to it will not jeopardize the others or completely cut off and isolate an important railway district—is in my opinion an essential feature in connection with any large railway electrification project.

As to the suitability of electric operation of railroads in Cape Breton Island, it should perhaps be mentioned that the locality is subject to numerous heavy sleet storms which might constitute a drawback not met with elsewhere in the same degree as here, but the experience of the Sydney and Glace Bay tramroad seems to indicate that this feature of local climatic conditions does not present any insuperable obstacle.

MR. A. J. TONGE: I was reminded by the remarks of Mr. Wright and Mr. Collins of the electric railway which was built some twenty years ago in Lancashire. It was constructed as an experiment, and went through a residential part of the country. During the war it was extended into the heart of the coal mining district of Lancashire, the most thickly populated county in England. I think the cost of coal may have had some influence in bringing about the extension during the war, but another factor may have been the relief in the carriage of coal of other and congested railways during the war period.

MR. MCFADDEN: I now believe the whole length of the Intercolonial Railway could be electrified and 25% of to-day's coal consumption on the railways thereby saved. Generating stations could be built, one in Cape Breton, one in Pictou County and one in Cumberland County, and the transmission lines extended to meet electric current generated by water-power in the Province of Quebec.

MR. J. H. CUNNINGHAM: Mr. McFadden's paper suggests the advantages that electric operation would have given to the

coal and steel industry in this part of Nova Scotia during the past winter. It is difficult to estimate the loss of efficiency and the restriction of transportation facilities caused by the difficulty of getting coal and the freezing of water pipes. The electric locomotives do not have to return to the round-house for coal and water; and electric operation of railways would seem to be suited to the local climatic conditions.

A lengthy discussion then ensued regarding the advantages and disadvantages that might be expected to follow electrification of the Canadian Government Railways. The President remarked that no doubt electric power would be more extensively used in transportation in the future, particularly in thickly populated districts. While all agreed that great saving would result from electrical operation of the Canadian Government Railways, the question that would first arise would be what amount of money is required to make the change.

Colonel Cantley foresaw a number of practical difficulties which would present themselves in practice, and he was afraid that the snow conditions would be found more difficult in Nova Scotia than was the case on the Western railways which had been referred to by previous speakers. Snow in the Maritime Provinces was of a different consistency to the snow in the highlands of the West, and made a drift which was more difficult to break through.

MINE FIRES: THEIR ORIGIN, DANGER, AND CONTROL

By Alfred J. Tonge, General Superintendent of Mines, Dominion Coal Co., Glace Bay

(Annual Meeting, Mining Society of Nova Scotia, May, 1918)

Having been asked by the Executive Committee of the Society to give a paper on the subject of Mine Fires, I have endeavoured to comply with the request by bringing together, under the title of "Mine Fires: their Origin, Danger, and Control," a few of the accepted facts and theories together with a few notes gleaned from my own experience.

Origin of Mine Fires

On the subject of origin there is much to say, but not much that can be said here. The diagnosis of origin is chiefly important as a preventive of repetition. Some coals are prone to fire, as the sparks are to fly upward, but add to any coal sufficient heat for a sufficient time in the presence of oxygen and you will start a fire. These three essentials, heat, time, and oxygen, are just as necessary below ground. The fire is already laid; keep away from it any one of the essentials named and there will be no outburst. In the open spaces of the mine time and oxygen are ever present, and the heat may be supplied by such forces as friction, blasting, electricity, open lights, or an explosion. These are extraneous causes, but are none the less fruitful of disaster. In the more secluded and closed spaces of the mine fire may also be developing, and, having a sufficiency of oxygen and time, coal often produces its own third essential of heat. The spontaneous combustion of coal has formed the subject of many discussions and some commissions. Formerly it was associated with coals having an unusual abundance of iron pyrites. Consensus of opinion now leads away from that, and while some coals are much more liable than others to spontaneously heat up, it is found there is some quality inherent in the coal itself, and not of necessity associated with pyrites, that starts up the action. The whole of the mischief is the hunger and thirst after oxygen which

some coals have. In gorging this oxygen the coal rises in temperature, after passing a certain point, which is rapid, extensive, and, if not dealt with, alarming.

This avidity for oxygen which coal has at comparatively low temperatures is quite "a thing apart" from the chemical changes which take place when coal is actually burning, say, under steam boilers. One of the efficiency tests for steam boilers is the amount of CO_2 in the chimney gases, and any approach to 13 or 14 per cent of this gas in the flues would be considered highly satisfactory, signifying that no more cool air had been admitted under the boiler than was necessary and that consequently good evaporation would be anticipated. Not so, however, in the mine. The coal takes up oxygen voraciously without a corresponding liberation of CO_2, and any attempt to measure the action by the amount of CO_2 given off would lead to no results. The reaction shows itself first in a rise of temperature. An interesting feature has lately been brought to light by Mr. J. Ivon Graham, associated with Dr. Haldane at the Doncaster Laboratory. We have been accustomed to speak of the occlusion of gases in coal. Mr. Graham combats the theory that gas is simply occluded or contained in the pores of the coal, but that the gas is dissolved in the coal. He says: "The theory that the gas is simply contained in pores in the coal is evidently quite untenable, since it follows from the foregoing data that coal even at a temperature of 30 degrees Cent. may take up at atmospheric pressure over three times its volume of methane. The solubility in coal of other gases besides methane renders intelligible the surprisingly large amounts of those gases obtained by Bedson by means of a vacuum pump. The fact that coal dissolves nearly its own volume of carbon monoxide is of some practical interest, for it is evident that coal which has been for some time in contact with air containing carbon monoxide will give this gas off to a current of pure air, and so become a source of unsuspected danger to rescuers. On the other hand, air containing freshly formed carbon monoxide will gradually lose it in passing slowly over coal. This may help to explain the unexpected survival of men and horses after explosions and fires and the survival of many of the mice living in the zone of an explosion."

Prof. W. A. Bone, giving evidence before the Departmental Committee on spontaneous combustion in coal mines in 1913, referred to and appeared to confirm the conclusions arrived at by Messrs. Parr and Kressman of Illinois, who found in regard to coal that "in the first stage there was an absorption of oxygen up to 120 degrees C., then at 120 degrees the first signs of evolution of carbon dioxide and steam appear—the oxidation is not sufficiently vigorous yet to be autogenous—and then at 200 degrees C. it becomes autogenous and the temperature rapidly mounts until at 350 degrees C. or thereabouts actual firing begins." The same gentlemen have found by experiment that at a much lower temperature, viz., about 80 degrees C., coal absorbs oxygen very rapidly, producing heat, but apparently producing no chemical results. Now parenthetically, so to speak, just apply this to the case, say, of a steam pipe in a mine or in a fanway. The temperature of steam at 100 lb. pressure is 164 degrees C. Even the temperature of exhaust steam, which is 100 degrees C., is higher than that (80 degrees C.) at which the coal takes up greedily more oxygen and heats up rapidly. Hence any accumulation of coal around uncovered steam pipes is raised by such adjacent heat to a temperature where it has a great tendency to help itself to more.

Summing up the origins of fires, we have: (1) Spontaneous combustion; (2) Ignition of feeders of gas by shots; (3) Fires left by explosions; (4) Fires from naked lights in the mine, say either from electricity, from friction of ropes or wheels, from the sudden disruption of boxes or other timber; (5) Fires contributed to by superficial heat such as steam and later self-propelled to ignition point; and, lastly, (6) Fires having their origin on the surface and being conducted into the mine along the intake airways.

And so we are led to the dangers of underground fires.

Danger of Mine Fires

However interesting a surface conflagration, however ominous a forest fire, there is nothing to equal in its dire possibilities an underground mine fire. It would probably be correct to

say that although the dangers of fires underground may be varied, the factor which rounds them into one comprehensive danger is the really confined area of even a large mine. A mine is entered by a limited number of small passage-ways, and although these may "box the compass" in their number and direction after getting below the surface, they are all filled with air or gases at about normal pressures and temperatures; a few of them act as airways, and in or adjacent to these airways men are performing those feats of strength and endurance associated with the avocation of mining. Generally speaking, it is only where the air is conducted and moving that the men are working, and the same air that has entered by the one opening on the surface a few minutes—in the case of a new mine a few seconds—before, is passing the workman to sustain life and to carry off the vitiated air from exhalation and the gases that are liberated by extraction of the coal from its long resting place. It is true that probably by wise provision the air after travelling some distance from the entrance at the surface splits and branches off at cross roads into two or more currents, to meet again usually at a late point near the surface in the return passages. It will be seen that should this clear stream of air be fouled at its source or in its course by smoke from a fire, the workmen within a very few minutes may be coughing, choking, and struggling in a serious fight for air.

Or, for a second danger, let us assume that in some of the disused galleries of the mine a small fire has spontaneously started up and that perhaps by a slight change of barometer the fringe of a volume of mine gases in explosive mixtures just reaches the spot where the fire is quietly burning. There is at once—in the fraction of a second—a sudden ignition, an explosion, and an enormous rise in temperature and pressure of all the ignited mixture and surrounding atmosphere. It is here again that the comparatively confined area of the mine renders the occasion a greater danger. These hot gases must find a vent or means of outlet. The floor, roof, and sides are too firm to yield. If only the lid would lift off, how much destruction might be saved! The only escape that the gases have is along the narrow passage-ways and rooms where in most cases men are probably working.

The temperature of ignition of firedamp is about 1200 degrees F., and in being raised to this extent it has been increased to a few times its original volume. The result is that the flame rushes out with a velocity compared with which an express train is slow. The velocity probably is in the vicinity of 1000 miles an hour. The next thing to happen is that receiving such a push from the rear the air in the roadways in front of the explosion is moved along under pressure and so forms—what I think Mr. Blacket of England was the first to call—a 'pioneer wave' which dislodges dust from the roof, sides and floor of the roadways, turning it into a cloud which the closely following flame again combines with, making a continuous series of explosions. No wonder that men, boxes, booms, doors, or other obstacles are swept aside, and then there follows the deadly afterdamp.

The Control of Underground Fires

Taking the first of the illustrations of danger referred to under the last heading—the fouling of the atmosphere by fire smoke: What can be done under such emergencies? If the fire is at or near the surface, say in the intake airways, there would be the stopping of the fan to consider or even the reversal of the air. A further suggestion would be the opening of the separation doors between the intake and surface at a point as near the surface as possible so that the smoke would be short-circuited as to its greater quantity and would pass out of the mine by way of the return without having traversed the workings. Some such scheme of short circuiting would probably be put in operation by officials further in the mine, and lives have been saved by such action and by the temporary barricading of a district so as to confine the air already in the district for use until exhausted. There is of necessity a limit to the time when men can survive such conditions, but it was applied at Whitehaven with the nearest approximation to success and has since been applied in America in more than one case. No time should of course be lost in getting the men from the mine, and a temporary closing of the roadway leading to the fire may be unavoidable and the most effectual step to take.

Or take the case of a spontaneous combustion fire which has been discovered before explosion has actually occurred. The occasion is perhaps described thus: Heating is taking place in some disused working. In spite of previous attempts at exclusion it is highly probable, nay certain, that air is passing into and consequently out of the area. The exits should be watched, and if the sense of smell and observation of heat are not sufficient, an analysis of the gas should be taken. The presence of heat or a trace of carbon monoxide would signify that practical efforts to curtail the danger must be made.

Although apparently paradoxical, the hot bed where the germ is developing should either be excluded from air or given a surfeit of it. If the area is strictly limited and accessible it may be advisable to open up the area and allow the heat to be conducted away, but this would only be after careful balancing of the circumstances, and ordinarily the process would be to seal up the area.

The interesting points in connection with sealing off such an area are:

(a) To maintain the prevailing conditions until the latest possible moment of sealing, or,

If the conditions of the fire have developed and are developing considerably to retard such development without unduly changing conditions in the area affected.

(b) To make full preparations including the proper stopping off of all subsidiary openings right up to the point of sealing up the main intake and return.

(c) To choose an opportune time for the final closing, when all men except those actually engaged at the sealing are out of the mine.

(d) To make the closing operations in proper order.

(e) To arrange test pipes for future analysis of the gases in the area.

(f) To make as expeditious an escape after sealing as possible.

(g) An explosion sometimes being almost unavoidable at such operations, to gauge the time when such danger is past and to consent to the readmittance of workmen.

There has been considerable controversy in the past as to the order of sealing off a fire zone. Probably the closing off first of the return side of the fire and secondly of the intake has a good many adherents among the practical mine officials of Nova Scotia. In spite, however, of such practised fire-fighters, and of the experience which has been theirs, and with all due regard for their confidence, which may be due to work successfully accomplished, I must place myself on record as an advocate under most conditions for the final process of the sealing off of a fire area to be the closing of the stopping on the return side of the fire.

This final closing might not necessarily mean the building of the stopping, but the closing of a pipe in the stopping; nevertheless the retreat from the mine should be the very next thing after the return stopping has been closed.

Even after the sealing off has been accomplished, the analysis of the gases behind the seals may cause further uneasiness.

In such case a rearrangement of ventilation reducing the pull of the fan across that section or an improvement of the main airways so as to reduce the water gauge may have the necessary effect in modifying the keenness in the fire zone and of filling up the fire area with gases that do not support combustion.

There remain still further conditions to portray, and remedies to discuss. Many occasions have arisen in the story of coal mining in Nova Scotia where a whole mine has had to be discontinued and closed off owing to the presence of fire which defies the most strenuous efforts.

Let us consider a few of the problems associated with such a closing up, and the interesting problem connected with reopening the mine.

The methods that may suggest themselves after the sealing up of the mine has been accomplished are:

(1) Flooding of the mine.

(2) Sand filling.

(3) Passing into the mine incombustible gases from the surface, such as CO_2.

(4) Making use of the gases that have accumulated in the mine since the sealing has been accomplished.

The effectiveness of the first of these methods is undisputed provided that complete submergence can be accomplished. It is not often, however, that all the conditions for adopting this method are favourable—in the case of rise workings, for instance, or where there are other connecting seams, which it is desirable should continue working. The effect on the roadways must also be considered; also the height that the water must be lifted when unwatering commences.

As for sand filling, there may arise occasionally an opportunity in, say, comparatively shallow mines, to apply sand flushing. Boreholes could be drilled in suitable positions, say around upper side of the district, and effective use made of the running in of sand.

The injection of carbon dioxide into the mine has been tried, the latest instance on a fairly large scale, being in connection with reopening of the Sengenhydd Colliery in South Wales.

It should be remembered that when a fire has once had a hold and the temperature of a considerable area has been raised to a high point, if the mine is of any considerable depth there is a great difficulty in cooling off, even after the fire has ceased to burn. The heat has difficulty in radiation, the surrounding strata absorbing for the time being most of it, but only too anxious apparently to unload it when the area is opened up again.

There may be occasions when the use of manufactured CO_2 would be absolutely the best instrument to have at disposal, but it would probably be found most serviceable in association with a properly conducted and controlled supply of air for

the men engaged in filling out the fire. At Sengenhydd, where fire supervened after the explosion of about three years ago, the chief difficulty appears to have been in getting the CO_2 to the spot and the greater fondness or affection for oxygen when it reappeared which the fire had. I think the engineer who had charge of the operations finally delivered himself of the expression—that "a plentiful dose of water and perseverance finally overcame the obstacle."

In a gassy mine, however, and where it has been necessary at an early stage to stop the fan so as to reduce the spread of the fire long before there can be a sufficient supply of CO_2 pumped into the mine, there will be creeping up to the fire another gas, which, while a non-supporter of combustion, nevertheless, found as it usually is in combination with the air, is highly combustible. Can you only get the combustion gases and air depleted of oxygen surrounding the fire, then you have thrown a blanket over it, which, with judicious treatment, you can utilize to wonderful advantage to recover the mine. But many anxious moments must be passed and certain precautions taken before the fire is enveloped by this atmosphere.

It will be found in a fairly gaseous mine where the fire has already taken a good hold that, within a comparatively short period after the sealing of the mine, the analysis of the prevailing gases would approximate probably to the following: CO_2, 8; O, 2; CO, trace; CH_4, 12; N_2, 78. This mixture would be an excellent blanket to have over the fire, and of course no active combustion with this envelopment is taking place. While the mine is filled with this inert mixture and while giving it an opportunity to cool off, careful observations should be taken and tabulations made to include barometric pressure, temperature (inside and outside), and hygrometrical readings; also, of course, analyses of the gases daily or oftener. Seals may have to be repaired and strengthened occasionally. Pipes with valves fitted through the seals are, of course, used for these observation purposes.

Having then a mine filled with deleterious, but in their combined form inert, gases, with the prospect that fire may

again break out when air is readmitted, and it being in every way desirable that the mine should be reopened, what procedure should be adopted ?

There has appeared in the Transactions of the Institution of Mining Engineers an account of a successful reopening under such conditions. This was accomplished entirely by the use of the so-called 'rescue' apparatus of the Draeger type. I would not care to disparage such work, particularly as, so far as the wearers were concerned, really hard, brave, and clever work was accomplished. I feel, however, compelled to say that it should only be after every other possible alternative has been discussed that their use should be allowed, and even then I would be inclined to look upon it as the last refuge of a despairing engineer.

The better method to be adopted is to treat the mine as a sealed chamber, to be kept perfectly quiescent and with its atmosphere undisturbed except for just that portion around and behind the recoverers, and which is their means of exit. It may be likened to the unpacking of a crate of valuable pieces of porcelain which are uncovered only as the unpacker reaches the individual pieces. To unpack the mine, it is necessary to carry a limited supply of ventilation along, to check it, guide it, and particularly to see that it does not get ahead. Many interesting and perhaps delicate situations arise, and the continuous assistance of the analyst, who should be on the spot, is necessary. A small exhaust fan and air pipes are in such operations essential. Seals on the front and flanks are erected as required. At the seat of the original fire, which is probably still as hot as one wants to have it, the water main should be handy, although as spare use of it as possible is perhaps wise.

It is further very essential that a very close watch be kept on the barometer, for the gases in the mine will be constantly expanding and contracting according to the fall or rise in atmospheric pressure. When at the seat of the fire or even in the fire zone it will be advisable to work only on a falling barometer and to temporarily seal off close behind the work immediately a reversal is noticed. By such procedure the inert gases are

tending to cover up the hot material being filled out, and there is no tendency on the part of the material to burst into flame as there would be on a rising barometer with the atmosphere tending to enter the area. At the time of a rising barometer the atmosphere immediately in front of the work may easily have been enriched by the admission of oxygen from the air, and the gases may now have changed to such a mixture as:

CO_2	4.6	or	CO_2	2.00
O	6.0		O	13.8
CO	.0		CO	trace
CH_4	7.59		CH_4	2.78
N_2	81.80		N_2	81.22

At or near the floor the oxygen may have stolen in unawares and caused the hot material to ignite, but a mixture such as that referred to above safeguards the situation. There being no necessity for the work to continue on a rising barometer operations should be suspended before this stage has been reached.

It should have been already stated that at least two ordinary smoke helmets equipped with bellows and about 200 feet of tube to each are among the most useful and necessary adjuncts. The same is to be said of electric lights. The hot material is filled out from under the fringe of the gases, the men meanwhile being kept supplied with the least possible amount of air to prevent discomfort. It is just here where danger lies of ruining the whole scheme and of possibly losing life, but observation and quick remedial measures in certain eventualities will almost certainly enable the operation to be successfully completed. It is here that one learns to appreciate the value of a reduction of oxygen, or an increase of CO_2 in mixtures that otherwise would be explosive. The 'Harger' mixtures assume to one who has been through such experiences practical form, and command respect by their reliability and consistency, for although working in atmospheres almost continuously containing around 10 per cent of firedamp and occasionally having actual visible fire adjacent to the work, no serious effects may result.

It will be observed that filling out of the fire has been referred to. This is a favorite remedy of many engineers, and it is difficult to find a better when it can be adopted.

Although, as said at the beginning of these few detached remarks, there is nothing so dire as a mine fire in its possibilities, and although at the time of losing a mine from such cause many hopes are dashed and past good work is buried, yet, when the arduous and hazardous task of reopening has been accomplished without accident, there emerges from out of all the disappointments something brighter. There has been to the individual the opportunity to work with loyal and almost fearless men, and there has been added to his chapters of mine experiences another chapter which has enriched the volume.

DISCUSSION

MR. F. W. GRAY: I believe that a great deal of the trouble in connection with breathing apparatus has arisen from the conflicting claims of rival manufacturers, as there is practically no difference in the principle of the standard types of apparatus. The Bureau of Mines of the Unites States has for some time past been working on the elaboration of a standard apparatus, combining the best points and as far as possible avoiding the bad points of the existing types. This apparatus is to be presented to the mining profession free of patent restrictions and royalties, and the 'Bulletin' descriptive of the Bureau's experiments is to be commended to all persons interested in breathing apparatus.

Mr. Tonge's paper on "Mine Fires" represents the mature opinions of a mining engineer who has had a unique experience with colliery fires, and any critical comments upon his conclusions are difficult to those whose experience has been less extensive and confined to reading and observation from a distance.

The paper sums up the more important origins of mine fires, but in dealing with their danger and control it touches more

extensively on fires of serious dimensions, and particularly enlarges on fires preceded or followed by explosions and fires arising from spontaneous combustion.

A proportionately large number of the fires which have taken place in the workings of Nova Scotia collieries, have originated from the careless use of naked lights and from the friction of ropes or wheels. Instances of this character which may be quoted include the fire at Caledonia Colliery in 1894; the fire at Dominion No. 1 Colliery in 1903; the fire at the Hub Colliery in 1906; a fire at the Albion Mines in 1913 caused by an over-heated brake-drum; and the ignition of the coal face at Sydney Mines in 1908 by a 'hung-shot.'

All these fires could have been extinguished in their beginnings had it been possible to reach the focus of the fire with water or with some form of chemical extinguisher before they assumed uncontrollable dimensions, and in this connection it would seem very desirable to have at hand some device which would make it possible to penetrate the seat of an incipient fire as quickly as possible.

It was with this idea that the Dominion Coal Company in 1907 purchased a number of breathing apparatus of the Draeger type.

Mr. Tonge in his paper expresses the opinion that breathing apparatus should not be used in recovery work under dangerous conditions until every other possible alternative has been discussed. and that even then he would be inclined to look upon their use as "the last refuge of a despairing engineer."

Mr. Tonge's criticism of the use of self-contained breathing apparatus is without doubt, based upon the number of fatal accidents which have accompanied their use.

There has been a very considerable misconception of the true uses of breathing apparatus, and it was most unfortunate that these devices should have been misnamed 'rescue apparatus.'

The self-contained breathing apparatus is undoubtedly in its infancy, but its development has been retarded by an exaggerated idea of its present possibilities, and ignorance of its limitations.

The self-contained breathing apparatus was designed to enable man to exist and to work in places where he is by nature unfitted to go, to live, and to work. The history of human progress is one of trial and experimentation, and in the fight against the limitations which nature has imposed upon our physical capacity, man's progress must be paid for by life itself.

A consideration of the history of the development of the aeroplane and submarine afford an interesting parallel, and, as has recently been pointed out by a very sane bulletin on the development of breathing apparatus issued by the United States Bureau of Mines, it is not surprising that the evolution of breathing apparatus should have been accompanied by fatalities, because it is quite as abnormal to man to penetrate the smoke-filled and poisonous passages of an exploded or burning mine, as it is for for him to fly among the clouds or to explore the depths of the sea.

The bulletin of the United States Bureau of Mines referred to states that during the seven-year period from January 1st, 1908, to January 1st, 1915, the Bureau Rescue Corps had attended a total of 283 mine disasters in which 2,700 lives were lost. Breathing apparatus was worn by 699 men; 92 miners were saved by apparatus men in the service of the Bureau; 768 were saved by other rescuers, and 1,426 miners escaped unassisted.

The bulletin states that the Bureau of Mines Rescue Corps has never consisted of more than 30 men, and during the period of five years four men of the Rescue Corps lost their lives while wearing apparatus.

During the course of the present war not only has there been a widespread use of gas masks (which, of course, are designed for a quite different object), but there has been an actual use of self-contained oxygen breathing-apparatus on a scale absolutely unprecedented in mine recovery operations. We may expect

that, when the experiences of the war are collated and made the subject of investigation in peace time, our knowledge of the possibilities of these devices will be much enlarged.

While the present type of breathing apparatus has admittedly many defects and while its use is not unaccompanied by danger, it undoubtedly has a place and a future in the equipment of a colliery.

For reconnaissance purposes, as an adjunct to a colliery fire brigade, for judicious and intelligent use in the recovery of an exploded mine; in the building of stoppings and the work of restoring ventilation, and as the *avant courier* of the rescue parties, self-contained breathing apparatus has its well recognized value, but it is not a universal panacea, as some people seem to think.

Breathing apparatus are nicely regulated, delicate mechanisms not yet fully developed to perfection. They must be used only if in good order, with discretion, and by trained selected wearers of good physique with the other essential qualifications of courage and intelligence.

MR. R. ROBERTSON: I very heartily agree with Mr. Gray regarding the necessity of having special apparatus to attack mine fires instantly they are discovered. I happen to have been closely connected with some mine fires that have occurred locally. In the case of the Hub Colliery fire in 1906, if we could have penetrated into the pump-room situated only a short distance from the shaft bottom we could have put out the fire, but we could not penetrate the smoke. In the case of a fire at Sydney Mines in 1878 we got to the fire shortly after it was reported, and if we had had water we could have put the fire out in a few minutes. These occurrences have strongly impressed upon my mind the importance of having some device to attack mine fires in their earliest stages.

MR. A. J. TONGE: It was not my intention to make so wholesale a condemnation of the 'Draeger' apparatus as to condemn it for every purpose. Those who took the trouble to read the paper will notice that I was simply dealing with certain

phases of mine recovery. There were no lives at stake. It was a question simply of the recovery of property after a mine had been sealed off, and this point should be borne in mind. I would like to thank Mr. Gray for the courteous way in which he presents his case. I know he has considerable feeling for the 'Draeger' apparatus, as I know of certain features attaching to its introduction into Nova Scotia. I feel he does not want to see the apparatus criticized without at any rate expressing his views as to why they were introduced and as to their real object. He refers to a bulletin issued by the United States Bureau of Mines and the number of lives stated therein to have been saved by the use of breathing apparatus, compared with those saved by the 'bare-faced' men. I would certainly have no hesitation in putting a very strong note of interrogation opposite the figures that have been quoted to the credit of breathing apparatus. You cannot class them so easily as all that. I am fairly sure there has not been a careful diagnosis of how these lives came to be saved, or whether they would not have been saved by 'bare-faced' men or have saved themselves even if the 'Draeger' men had not been there. I would like to give an illustration of a case considered a successful one in the Old Country.

[Here Mr. Tonge referred to a case in England, where rescue operations were suspended until arrival of Rescue Corps from town. Only a proportion of a small party were eventually rescued, when all probably would have been saved by other and prompter methods.]

The number of occasions when lives have been saved by the oxygen apparatus are so few that they have been made the most of by those who are strong supporters of it. I think as mining men we ought not to take too much for granted. This is one of the things that comes to us from Germany. As you know, organization is such in Germany that if it were once instituted it would be pushed to its extreme limit. Even in Germany, where the system has been introduced thoroughly, the number of individual lives saved, so far as I have been able to find out, is practically nil. Just imagine what happens after an explosion—for it is necessary to comprehend the whole position before you

can tell how far these apparatus are likely to be useful. A mine is often imagined to be like a bottle where you only have to go through its neck, and when you get inside find all is right. If it were, and you could get your 'apparatus-men' through the bottle neck, they might be able to save life. That, however, is not the condition of a mine after an explosion. Ventilation after an explosion is often very quickly restored in the outbye parts, but not in all parts of the mine. One of the chief dangers after an explosion is the prevalence of fires left by the explosion. This is where the time lost in waiting for the so-called rescue brigades and in the limited extent of their operations becomes so potentially disastrous. The right man for that occasion is the untrammelled man, the manager or his immediate under officials. He is the man to go into the mine and see its condition quickly and to assist accordingly. There is a waste of valuable time if you insist on the apparatus. The next danger is a second explosion; but it is just as much a danger to the men wearing apparatus, and there must be all the saving of time possible. I regret to say I could name several instances where lives have been lost by relying upon the use of the apparatus. In the old days men would go down the pit and rescue a man and say nothing about it. To-day, if a life is saved by the assistance of the apparatus, all the world knows about it. The American figures, as already said, certainly so far as I am concerned, must not be taken for granted. Further, there have been a good many cases of loss of life in wearing this apparatus, Some of the strongest and physically finest men and instructors have succumbed when wearing the apparatus—some of these within the last three months. There was a case in Nova Scotia only a very short time ago, where such a man lost his life through a momentary fear that he was overcome while wearing the apparatus.

If this apparatus, having taken up so much time and attention to the exclusion perhaps of other things that might possibly be put into its place, has not come up to expectations, it is our duty to examine thoroughly what reliance can really be placed upon it and to carry our investigations further than they have yet been carried.

The other point was with regard to fighting mine fires. We have to remember the apparatus can not be used with effect in a temperature of over 80° Fahrenheit. This is a low temperature about a fire. There is not only temperature to consider, but steam and moisture. For fighting mine fires there is nothing to equal the smoke helmet. This is just put over the head, fastened round the neck, and fed by a tube which leads back to a pair of bellows. The bellows are placed in the fresh air. The pressure is positive inside the helmet, and there is no possible chance of the outside air getting into the helmet. The advantage of these helmets in trying to fight a fire is enormous, because the hotter the place worked in, the cooler the air seems to be to the person being fed with it, and the more pleasant the feeling.

Now in regard to the question of sealing off mine fires. The paragraph in which I mentioned the return, it will be noticed, had reference to sealing off a gob fire. It did not refer to a casual and sudden fire. It was in connection with a fire that had been in a mine for days, perhaps weeks. This was the one it was proposed to seal off, and under those circumstances the sealing off of the return air should be the last operation. I think also in this I would have the support of most of the mining engineers of the present day.

Why stop off the return last? I think we should get it properly in our minds that the two fires—gob fires and open fires—are different things. In a gob fire you have to assume there is a shortness of ventilation in the interior of the workings where the fire exists. You have to try and picture the conditions as they exist. It is a slow fire. It can scarcely be seen. It is so short of air that it cannot break out into flame, but just the same it is a danger and is capable of igniting gas if any comes near it, and you want to close it off. Immediately you close off either the return or the intake you have to assume that there is a stoppage of air right at the fire itself at the moment. We will assume that you have a fire right in the centre of the district. On the intake side the air is going very quietly up to the fire, feeding it and passing on in the form of CO chiefly and steam, and possibly hydro-carbons, which are highly inflammable. We stop the intake first. What happens? This, at least, we

have to assume is what takes place: The fire immediately falls—it is short of its intake, and has a slight tendency to die down. In the meantime, these highly explosive gases, carbon-monoxide and hydro-carbons, are passing quietly away from the fire. For the moment you have to exclude all ideas that CH_4 is your enemy. You have to deal with something that is a product of the fire. It is the CO and hydro-carbons forming at the fire. These hydro-carbons have a tendency, being lighter, to pass to the return. They have a greater tendency to get away from the fire than under any other conditions. Reverse that. Stop your return first. The inflammable gases back down on the fire and you have your explosion. That is the danger you have to avoid.

In the case of an open fire it is just the reverse. It is a question of what is the blanket that is going over your fire. In the case of the open fire, if there is nothing more than carbon dioxide it may be the best blanket to bring back over your fire, so in that case you would close the return first. Quite apart from the question of danger from CH_4, it would be the best way to put it out.

Following Mr. Tonge's remarks, an animated and very technical discussion* took place as to whether in the case of a mine fire it is better to close off first the intake or the return air. First-hand personal experiences in connection with mine fires in Nova Scotia were related by Mr. John Johnstone, lately retired from the position of Superintendent of Mines for the Nova Scotia Steel & Coal Co.; by Mr. J. D. Maxwell, Assistant General Superintendent of the Dominion Coal Company; Mr. Alex. McEachern, Superintendent of No. 4 District for the Dominion Coal Company; Mr. Neil Nicholson, the Deputy Inspector of Mines for South Cape Breton; by Mr. Robert Robertson, Manager of the Princess Mine of the Nova Scotia Steel & Coal

*The Editor regrets that the stenographic report of this discussion was incomplete, and has not permitted the preservation of a discussion of a most informative and valuable nature, inasmuch as it was carried on by men whose experience of mine fires in Nova Scotia was of a first-hand and varied character extending back to the early seventies.

Company; and by Mr. D. H. McLean, Manager of No. 9 Colliery of the Dominion Coal Company. A general preference was expressed by the members who took part in the discussion for closing off the return air first, and the impression seemed to have been formed that Mr. Tonge advocated exclusively the closing off of the intake air first. As a result of the discussion it was made clear that while Mr. Tonge expressed a preference for closing off the intake air first, he made it clear that conditions existing in particular cases would govern the procedure to be adopted, with the general aim in all cases to utilize the products of combustion to blanket the seat of combustion and thereby cut off the oxygen supply to the fire.

MR. J. H. CUNNINGHAM: There is no more important subject for discussion in our Society than that of mine fires and explosions. The question suggests itself to me whether the subject might not profitably come up for discussion from year to year, and I would make the suggestion that a Committee should be appointed from among our members charged with the duty of laying down the principles that should govern our practice in dealing with fires and explosions. I think that well-considered rules and regulations might be a great help to men called upon to fight mine fires and to carry on rescue work after mine explosions.

THE PRESIDENT (MR. D. H. MACDOUGALL): Mr. Cunningham's suggestion is important, and a Committee might be appointed that could draw up and circulate to the members of the Society before the next meeting some recommendations along the lines he proposes that could be discussed at our next meeting.

MR. THOMAS CANTLEY: I feel I should say something in reference to the Draeger apparatus. I should be sorry if the idea was fostered that there is inherent danger in using the apparatus and that it should only be used in cases of absolute disaster. Under certain circumstances I believe the apparatus has proved to be of considerable advantage, but it should of course always be ascertained whether a man is capable of wearing and using the apparatus before he descends a mine for that purpose.

NOTES ON THE ADVANTAGES OF EFFICIENT COAL WASHING AS REFLECTED IN THE MANUFACTURE OF IRON AND STEEL

By W. H. Graham

(Annual Meeting, Mining Society of Nova Scotia, May, 1918)

Coal is the standard by which the nations of the world are classified as to their present power and future progress. It is a remnant of the flora from past geological ages—organic matter which has undergone chemical changes, and to which (usually to its detriment) have been added mineral impurities.

The combination of the chemical elements of coal is unknown. We can, however, determine the proportion in which they occur. The most serious impurities with which we have to deal are various forms of slate or shale, and sulphur: and it is to the advantages to be derived from the reducing of these by scientific crushing, washing and classifying of the coal, I propose to refer.

In practice, the separation of dirt from coal is effected by taking advantage of the difference in their specific gravities. The specific gravity of soft coal varies from 1.25 to 1.35. Dirt, namely—shale, fire clay, sandstone, etc.—varies from 2 to 2.7. Iron pyrites will range from 4.8 to 5.2.

Some coals cannot be washed as advantageously as others, and no definite figure can be given as to the average possible reduction of ash and sulphur. For instance—when coal contains sulphur or ash as an organic compound, intimately associated with the carbon, improvement is difficult. These, however, are rare exceptions, as most coals can be materially improved by washing, and a very simple laboratory test can be used to prove to what extent.

Sulphur is the iron and steel-maker's worst enemy. It is possible to make good pig iron with high sulphur coke, but it is not possible to maintain a uniform sulphur and silicon content in the iron unless the ash and sulphur are running regularly in the coke. For instance, if the blast furnace

superintendent charges his furnace (assuming 1.20% of sulphur and 5% of ash in the coke) and gets coke containing 1.60% sulphur and 10% ash, as soon as this coke of lower calorific value reaches the reduction zones in the furnace, the chemical reactions are immediately arrested, the furnace starts to grow cold, the silicon goes down, and the iron takes up the sulphur (on account of the fact that the slag, which is now too lean, has reached the sulphur saturation point). In other words, we have a cold furnace, making high sulphur white iron.

If, on the other hand (on the assumption that he is getting 1.60% sulphur and 10% ash in the coke), he has charged his furnace with the necessary lime to flux and absorb these impurities and he unexpectedly gets a run of especially good coke, the furnace gets too hot and the chemical reactions are intensified, resulting in a sticky, limy, slow-working furnace, and silicon too high for basic iron.

In either case, it ultimately means loss of output, and spells high cost and trouble all along the line; so that what the blast furnaceman wants is not only *good*, but, what is far more important, *uniform* coke, in order to produce uniform, low-sulphur, standard pig iron.

No one has yet discovered how to make good forging or rolling steel from high sulphur pig. Hence it follows that the place to fight the sulphur evil is where it is first met—in the raw coal.

The detrimental effect on outputs and costs, due to the cutting down of all capacities by carrying an excess of ash through the various operations, must be obvious to everyone.

In former times, the method of treating raw coal for metallurgical purposes consisted simply of dry screening and hand picking—the small coal was left as refuse. With continually increasing competition and the advent of additional small coal on account of the use of mining machines, it became imperative to recover every particle of coal in order to make it contribute its share to the cost of mining. Thus, from a crude process—which was really that of an ore washer reversed—we have the highly perfected coal washer of to-day.

The Nova Scotia Steel and Coal Company was probably one of the first companies in America to wash coal for metallurgical purposes. They have been doing this with various types of washers and with varied success for the past twenty-five years. However, rather than dwell on the experiences of the past, I shall refer briefly to the results obtained with their latest installation put in operation some three years ago at Sydney Mines.

This plant consists of a washer of the Baum type, designed by Messrs. Simon-Carves of Manchester. It is capable of washing and classifying from 75 to 90 tons of raw coal per hour. The outstanding features of this plant may be noted as follows:

1. The principle of washing, then classifying.
2. Actuating the washing water with compressed air.
3. The automatic recovery of slurries, draining and mixing these continuously and uniformly with the fine coal.
4. Clarification of washing water for re-use.

The necessary pulsation is given the washing water and the raw coal in the wash boxes by exhausting compressed air through the beds. Compressed air, while it is the cheapest, is also the most elastic and energetic agency yet known to keep materials in the washing box in suspension. There is the energetic upward stroke of the washing bed, then the slow, gentle downward movement, giving the various materials ample time to classify in accordance with their specific weights. The dirt, sinking to the bottom, passes away through the screens and gates in the washing box while the light coking coal and the heavier middles or boiler fuel coal flow over the top and are further classified—the middles going to the boiler (or in storage bins) and the coking coal passing over a classifying screen, where it is further classified according to size and passed through a secondary washing box where the sulphur and fine slate are further discarded. The clean coal is then flowed to the drainage conveyor.

The coarser coal in the conveyor, on which the slurry is filled, acts like a filter for the fine dust, retains all coal matter, and at the same time clarifies the water—the latter draining through the perforated conveyor buckets. The amount of moisture left in the coal depends on the size and speed of the conveyor. The one to which I refer travels at a speed of about 50 feet per hour, delivering the coal to the disintegrators, where it is thoroughly mixed and broken to the desired fineness.

The washing water is kept at a uniform clarity by continuously passing it through a large settling tank. This tank arrangement is the reverse of the usual method where it is in the basement of the washer. In this case, it consists of an elevated cone about 80 feet high, supported on a cylindrical wall. This elevated tank is automatic, without any moving machinery. Owing to its being circular, the motion of the water at even distances from its centre is uniform—thus avoiding local eddies, which would disturb the settling of the slurry and allow it to be carried in suspension back to the washer.

Only one pump is necessary, and all washing water flowing to the washer comes from the tank at a constant pressure. The importance of this feature requires no further comment.

This plant is at present operating on various slack coals running from 1.80 to 2.75% sulphur and 12 to 15% ash. The low sulphur coals can be washed down to 1% sulphur and 3% ash, returning 78% coking coal, 10% middles or boiler fuel, with 12% discard.

In order to get a uniform produce, the sulphur content in the low sulphur washed coals is adjusted to the lowest practicable point obtainable in the high sulphur coal, resulting in an average product running between 1.20 and 1.25% sulphur and 3.50 to 4% ash, returning 80% coking coal, 8% boiler fuel, with 12% discard. The analysis of the coke produced from this coal will average about 1.10% sulphur and 6 to 7% ash.

The advantages to be derived from using a fuel washed to the lowest feasible sulphur and ash content, may be summed up as follows:

In the Coke Ovens: Increased coking capacity resulting from the increased gas value per pound of coal charged.

In the Blast Furnace: Improvement in the quantity and quality of the output, due to the higher calorific value of the fuel; and decrease in lime burden otherwise necessary to flux and absorb excess sulphur and ash.

In the Open Hearth: Increased output and improvement in quality, due to uniform control of silicon and sulphur content in the pig iron, which has the greatest variation of any of the materials used in the open hearth process, and has an important bearing on the time necessary to finish the steel.

Referring in detail to the above mentioned advantages, and starting with the coke ovens—we get an increase in the capacity of the ovens. Assuming a raw slack of 12% ash and 2% sulphur, and a washed product of 4% ash and 1.20% sulphur, we get an idea of the saving which might be expected—as follows:

	Analysis Raw Slack	Analysis Washed Slack
Volatile	35%	38%
Fixed Carbon	53%	58%
Ash	12%	4%
Sulphur	2%	1.2%

Coke from Raw Slack		Coke from Washed Slack	
Carbon	81.5	Carbon	39
Ash	18.5	Ash	6.6

Since the heating value of coke is only in the carbon, this means an increase of 14% in the calorific value of coke from washed coal compared with coke from an equal weight of raw coal.

It also means an increase of 8.5% in the volatile matter, which is an increase of approximately 8.5% in the volume of gas derived from the washed slack in the ovens over that derived from the raw slack. These figures are approximate as no account has been taken of a certain amount of volatile,

combustible or gas-producing constituents in the coal, which is occluded in the coke, during the process. This would be true in either case, and is controlled within narrow limits by the temperature of the ovens, and other local conditions.

There are other variable conditions, but in practice the theoretical figures given furnish an available working basis for comparison; and we shall not be far astray in stating that a coal washed to the extent shown above, produces 4% less coke—giving a consequent increase in oven capacity and yielding a coke 14% better in heating value, accompanied by 8.5% increase in gas volume—all from the same initial weight of washed coal as compared with raw coal.

In the Blast Furnace: The increase in the calorific value of the coke comes immediately into service in the blast furnace working. As stated, the heating value is 14% greater from a material 4% lighter, or, in other words, the thermal value per pound of coke from washed coal is 18% higher—which shows an even greater fuel economy for the same ore burden.

Bearing in mind that coke performs two functions in the blast furnace, namely—as the chemical reagent for the reduction of ore according to the equation: $3C+Fe_2O_3=2Fe+3CO$; and as a fuel to produce heat, it becomes evident that the fuel saving on this account will not be 18% of the total coke, but 18% of the coke whose function is that of fuel. This means that with the same weight of fuel we can have a proportionate increase in pig iron production, because of faster driving and increased burden.

There is another factor to be considered besides simply that of heating value, namely,—the lessened ash and sulphur content, which has to be fluxed. A decrease in the total ash from 18.5 to 6.6% and in sulphur from 2 to 1.15% (or any portion of these decreases) means a correspondingly lessened lime burden, with consequent reduction in coke consumption per ton of iron; or increased ore burden and greater output.

The simplest burden calculation based on local prices will show a startling variation in the cost of iron, due to the sulphur

and ash content in the coke. As a matter of fact, experience has shown that these figures will be tremendously increased in practice.

There is another still more important factor, which has an even greater bearing on the operating cost, and that is the question of temperature control in the blast furnace—difficult with uniform coke, but impossible without it. Every furnaceman fully appreciates the important bearing that uniform coke has on the quantity and quality of the output—particularly where the iron is being made solely for the production of basic open hearth steel.

We might note here that a furnace that is running irregularly—as it must necessarily do unless the raw materials are reasonably uniform—will produce not only bad iron, but bad slag. (Blast furnace slag in this district will run by weight in the ratio of about two to three compared with the iron output.) The percentage of iron in the slag depends on the furnace control. When producing No. 1 basic iron, the slag will be found to contain not more than 1% of iron; while the slag from a cold furnace making high sulphur iron will usually contain as much as 8 to 10%. This is the place to look for the ore stockpile shortage.

Passing to the open hearth, and following the cycle of operations through this department, we shall try to demonstrate the value of uniform pig iron. The factors that are here to be considered are by far the most complicated, and, to simplify matters, we shall confine our remarks to but one method of open hearth practice, namely, the iron ore-scrap process, using molten iron. This consists in charging the empty furnace with limestone, ore (or mill scale) and scrap, heating this to a point where the scrap flattens in the furnace, and then adding molten iron, whereby a reaction is set up between the metalloids of the iron and the oxides in the original charge, which develops some heat—possibly 35% of that necessary to produce steel. The metal is then brought to the casting point with the least possible delay. It is therefore apparent that a change in the metalloids of the pig iron must mean a corresponding change in the amount of oxides of iron originally charged or added to the bath. Like-

wise, as these metalloids (with the exception of carbon) are slag-forming elements, it follows that there must be a corresponding change in the amount of limestone or flux originally charged. These are the features that make the process complicated, and under which the human element breaks down.

Now, we shall consider briefly the outstanding features in relation to this process. Pig iron high in silicon gives a bath which is hot and high in carbon when melted. (It must not be too high or it will seriously attack the open hearth basic bottoms.) A pig iron low in silicon gives a cold, sluggish bath low in carbon. In one case, the oxides are not sufficient to take care of much more than the silicon, and in the other case they are in excess. In practice, we cannot more than approximate the oxides required, as some must of necessity be formed from the scrap charged during the original heating process. In a steel which 'melts soft'—to use the open hearth man's phrase—we have a bath charged with an excess of oxides; in a steel which 'comes hard,' we have a bath with little oxides, which means that we must add oxides to the slag, where they are not nearly as efficient as on the furnace bottom, because they become dissolved in the slag, and are not in as intimate contact with the metal; and again before we are through we get a bath charged with an excess of oxides, which produces poor steel, high in rejections in the rolling mill and forge. This we can attribute in part to non-uniform pig iron.

Likewise, in either case above considered, the steel-making time is tremendously increased, giving us another serious count against variations and lack of uniformity.

So we complete the cycle, not in its entirety, but touching some of the high spots, believing that those interested can follow the simple lines of reasoning and calculate the advantages in accordance with their local conditions.

Before concluding, we might refer to the advantage to be derived from the washed product in its relation to powdered coal. Some eminent engineers tell us that the only economical way to burn coal is in the powdered form. If this be so, it will be readily apparent that the material before powdering should

be refined to the highest calorific value and lowest sulphur content. The advantage of powdered coal in lime and cement kilns has already been clearly demonstrated. Recently, there has been considerable development in the use of this material in the open hearth practice—some of the original installations being so apparently satisfactory that duplications have been ordered and installed; but some of the results in this field have been very disappointing. The difficulties would have been greatly minimized, or perhaps would never have existed, had the coal been efficiently washed.

In conclusion, we believe the initiated will concede that a careful preparation of the raw coal is one of the most important refinements in the iron and steel industry, and must necessarily show a tremendous saving in the various departments—in accordance with the degree of efficiency with which it is carried out—while in many cases it may mean the difference between success and failure.

DISCUSSION

MR. C. M. ODELL: I notice Mr. Graham's paper mentions that in washing coal there is a certain percentage of loss. Is there any attempt to utilize the discard ?

MR. GEO. D. MACDOUGALL: In Mr. Graham's absence I may say that I believe his paper was intended more particularly to deal with effects of the proper washing of coal from the metallurgical point of view, rather than as a paper on coal washing. The Baum washer is particularly designed to conserve coal and to recover the fines. Mr. Graham's paper is of particular interest to men engaged in the manufacture of iron and steel, and I have much pleasure in moving a vote of thanks to Mr. Graham.

COL. T. CANTLEY: I think the Nova Scotia Steel & Coal Company was the first to wash coal commercially in this Province.

Twenty-eight years ago Mr. Graham Fraser, the father of the iron and steel trade in Canada, took five tons of coal from the Drummond Colliery and had a washing test made by Schumacher, one of the leading engineering firms in Germany. This was followed by another test of a lot of 40 tons, which was successfully coked and used in a blast furnace. The result of the tests was the decision to erect a modern washer designed to deal with Pictou coals. Eighty beehive ovens were also installed and went into blast in August, 1891. The washer differed very little from the Baum washer referred to by Mr. Graham. A later washer erected at Sydney Mines proved to be nothing like as efficient as the first washer at New Glasgow, and there was practically no difference between this pioneer washer and the latest Baum washer except that the older washer was operated mechanically whereas in the later washer compressed air was employed to give the washing impulse. As Mr. Graham states there have been improvements in drainage, but I think I am quite safe in saying there has been no fundamental improvement over the 1890 washer. I have no very great regard for Germany, but in all fairness I think we must say that the Germans have a capacity for working out and improving upon the original ideas of other peoples. The Germans have made the coal washer as efficient as it is to-day, and beyond the first conception the whole thing is of German development.

The best coke we ever made at Ferrona was Springhill and Albion coal mixed half and half. Cape Breton coal ran high in sulphur as compared with Pictou coal, and when the question of broadening out the operations of the Scotia Co. arose, it was evident this could not be accomplished in Pictou County, and the possibility of utilising Cape Breton coal for metallurgical processes was looked into. On the dumps in Cape Breton we had 100,000 tons of slack coal with no market whatever. There was a great deal of slack left down in the mine also. It occurred to us that this slack could be utilized if the sulphur were reduced by washing, and we took the matter up with Mr. H. M. Whitney, as a result of which 18,000 tons were sent to Pictou. After washing and coking we made the best of iron with the help of this Cape Breton coal.

The President (Mr. D. H. McDougall): In answer to Mr. Odell's question about refuse I may say that the manufacturers of the Baum washer before the War were willing to guarantee that the free coal in the discard should not exceed three per cent. The early history of the coal washer in Nova Scotia, as related by Col. Cantley, is, as a matter of fact, the early history of the coal washer on this continent. We had to be far in advance here, and were so.

Mr. F. E. Lucas: I believe uniformity in coke is very desirable in blast furnace practice. I agree with Col. Cantley in regard to the development of coal washing in Germany. Necessity is the mother of invention, and the German coals are unfit for metallurgical uses without treatment. To date we have not found it necessary to compress coal for coking.

Col. Cantley: I was interested in Mr. Lucas' remark on compression of coking coal. The life of the coke oven is practically doubled if compressed coal is used. I know of no field in connection with the manufacture of iron and steel which offers as wide an opening as the improvement of coking processes.

Mr. Lucas: The capacity of an oven is cut down by compression. I have in mind one plant in England where compression was abandoned after years of experience. Different coals do not give the same results under the same treatment. Some Illinois and Pittsburgh coals were considered at one time as hopeless from a coking point, but to-day they are getting results from these same coals almost equal to those obtained from Virginia and Pocohontas coals. My own experience inclines me to add that compression is something to be avoided.

Col. Cantley: We have found by practice that at Sydney Mines that we were able to get a 40% increase in the quantity of coal that we could put into an oven, and this at no cost except for the stamp.

Mr. G. D. MacDougall: Mr. Lucas is referring to by-product ovens, but Col. Cantley has in mind, I think, ovens of the non-by-product type. This may account for some difference of opinion.

DISTILLATION OF COAL

By F. E. Lucas

The writer believes the day is within measurable distance when it will be made an indictable offence to burn a pound of raw bituminous coal. Then such grades of coal as can be coked will be turned into smokeless fuel and the gas and by-products recovered; and non-coking grades will be gasified in such a manner that the ammonia content at least can be recovered. When that stage is reached, power will be available in every manufacturing centre of Canada at a cost as low as that at which hydro-electric power can at present be sold in the Niagara district. There will, moreover, be made available motor fuel for internal combustion engines possessing superior qualities to the best grade of gasoline now produced; there will be ample supplies of bases for explosives, dye stuffs, and fertilizers, and also oils, tar, pitch, etc., etc., for wood preserving, road making, fuel, or any of the purposes for which these products are so well adapted.

The coking, or, to give it its chemical term, the destructive distillation of coal, is the heating of coal in a closed retort for such a time and at such a temperature as will drive off the volatile matter and leave a solid residue of coke. All the volatile matter is recovered and in turn made to yield its various by-products. The quality of the resultant coke and the purposes for which it may be used are dependent on the quality of the coal, the design of the oven or retort, and the heat treatment given.

Heretofore the main use for coke in this country has been for metallurgical application. The grave matter for regret is that such a large proportion of the coke so used in Canada has been made in beehive ovens, by which process not only is approximately 10% of the coal itself lost in raising the initial heat in the ovens, but all of the by-products and heating value of the gas are wasted. In addition to the present market or present use for coke there is a larger market which could be developed for domestic coke of a satisfactory grade and quality.

Coke for this purpose would need to be of a more open structure and higher in volatile matter in order to permit of rapid or easy ignition and free burning with the low degree of natural draught in ordinary household stoves and grates; and such coke can easily be produced in the modern by-product coke oven. Furthermore, for this purpose certain grades of coal could be used which, on account of their chemical analysis and physical properties, would be unsuitable for the production of metallurgical coke. The amount of volatile matter left in such coke as compared with that of the metallurgical coke would not appreciably affect the yield of by-products, but would in a small measure decrease the quantity of gas available for fuel or power purposes. This, however, from the standpoint of return on capital invested, would be more than made up by the shorter coking time required and the greater output per oven per unit of time.

The modern by-product coke oven for the production of metallurgical coke is built, so far as the coking chamber and heating flues are concerned, entirely of high-grade silica brick. This is necessary in order to withstand the extremely high temperatures needed to get the short coking time which is now the general practice. The oven chamber is approximately 34 ft. long by 17 to 19 in. mean width (the oven having about 2½ to 4 in. taper throughout the length to permit of easy pushing of the coke) and about 10 ft. in height. Between the walls of the ovens themselves are the heating flues, in which the gas is burned to provide the heat for the coking of the coal. The arrangement of these flues is such as to provide as uniform heating as possible throughout the entire length of the oven. The gases after burning in these flues are passed through regenerators on the way to the stack. Each oven or each battery of ovens have two regenerators, so that by reversing the course of the gas at stated intervals the two regenerators are alternately heated. While the gas is heating one regenerator, the air necessary for the combustion of the gas in the flues is passed through the other regenerator and so supplied at a high temperature, resulting in a very material saving in the quantity of gas needed to heat the ovens to their required temperature.

The coal, after having been properly prepared by crushing

or washing, as the case may be, is charged into the ovens by being dropped through four or five holes in the top of the oven chamber from an electrically driven larry running over the top of the oven battery and receiving its coal from an elevated coal storage bin. It may here be noted that for the production of the highest grade of metallurgical coke each kind of coal to be used should be studied and tested before a plant is built. Practically all coals will make coke of better physical quality by being finely crushed before being charged into the oven, while some coals, on account of the high ash or sulphur content, will require to be washed as well as crushed. The question of coal sampling, testing and preparation for coking purposes is a very large one, and cannot here be discussed at the length it deserves.

When the coal is charged into the oven, it is levelled by an electrically driven ram working through the upper part of one of the oven doors. It is most desirable, having regard both to the consideration of the output of coke per oven and to that of the highest yield of by-products, that the oven should be charged as full as possible, leaving just sufficient room over the top of the coal charge for the gases to travel the full length of the oven to the outlet into the collecting main. The charging hole covers are then replaced and carefully sealed with clay to prevent the loss of gas. At one end of each oven is a cast-iron stand pipe through which the gas passes from the ovens into a large main traversing the full length of the battery of ovens. Each standpipe is equipped with a valve, so that each oven may be connected to or cut off from the collecting main at will. After the required coking time is passed and all the volatile matter has been driven off, this valve is shut and the oven is allowed to stand for a short period of time before pushing. This wait is necessary, particularly so far as metallurgical coke is concerned, in order to harden the cell-structure of the coke so that it will stand the abrasion consequent upon the passage of the stock down through the blast furnace, smelter, or cupola.

The doors at each end of the oven are then removed by various mechanical contrivances designed for this purpose, and the full charge of coke is pushed out by an electrically

operated pushing ram. The general practice to-day is to receive this charge of coke in a specially designed quenching car, the car being moved at right angles to the travel of the coke while it is being pushed so that the charge is spread as evenly as possible over the full length of the car. This car, which may be handled either by electric or steam driven locomotive, or be self-contained in that it may be equipped with its own traction motor, is then run immediately to the quenching station, where it receives a heavy spray of water for a short period of time.

The bright silvery appearance so peculiar to beehive coke which is quenched in the oven is, in by-product coke, very much dependent upon the quickness with which the coke after being pushed can be placed under the water spray, for if it is exposed to the air long enough to become slightly oxidized it will, after quenching, have a much darker appearance, although such appearance in no way affects the physical quality of the coke. After the coke has received its spraying in the quenching station the car is conveyed to a sloping wharf, on to which the coke is allowed to slide from the car without any definite drop. On this wharf it remains long enough to cool and dry out, and is then run off on to a belt conveyer which carries it to the screening station. This screening station, when only metallurgical coke is desired, may be of very simple construction, such as a single screen to remove only the fine coke breeze and any dust or clay from the luting of the oven doors. If it is desired to make various grades of coke for foundry and furnace and domestic uses the screening station will, of course, be more elaborate, and equipped with various sizes and types of screens. From this screening plant the coke is either loaded directly into cars or placed on a stock pile, and the breeze is loaded into cars and taken to the boilers or wherever it may be needed for use.

The gas, after reaching the collecting main on top of the ovens, is drawn to the by-product building by exhausters.

There are three distinct types of by-product recovery plants, namely, those employing the indirect or scrubbing process, the semi-direct process, and the direct process, respectively.

In the indirect process, the gas is cooled down to at least 90° F. to remove the tar. There are many different types of tar-scrubbers, but the general principle governing them is the scrubbing effect given to the gas by friction against surfaces or through screens or liquids. In addition to this there is now in successful operation an electrical method of extracting the tar at any temperature, somewhat similar to the way in which dust is removed from furnace gases. After the tar is extracted the gas is thoroughly washed with water, which absorbs the ammonia. In general coking practice this water, known as ammonia liquor, contains about 1% of ammonia. In this type of recovery plant the efficiency of the ammonia recovery apparatus depends largely on the temperature of the gas and water, which must be kept as low as possible. After leaving the ammonia washers the gas is again passed through a second set of washers, where it is washed with oil to recover the benzol, toluol, xylol, naphtha, and naphthalene. The ammonia liquor is distilled by direct steam, and a small amount of lime added to break up the fixed ammonia compounds. The gases leaving the stills may be either passed directly through a bath of sulphuric acid, resulting in the formation of sulphate of ammonium for fertilizer, or they may be passed through dephlegmators and condensers giving a product known as commercial concentrated liquor containing from 16% to 25% ammonia. This in turn is redistilled and passed through various purifiers to remove all oil, CO_2, and sulphur, giving a pure dry ammonia gas which may be used for refrigeration purposes or for the production of ammonium nitrate with nitric acid; or the pure gas may be absorbed in distilled water giving the aqua ammonia of commerce. The oil in which the gas was finally washed contains about 2½% to 3% of light oil which is recovered by distillation by indirect and direct steam, and the oil returned for further scrubbing of the gas. The light oil is then subjected to fractional distillation and to acid and caustic washes to get the pure products desired.

In the semi-direct recovery process, the gas is cooled to remove the tar and then reheated, and all passed through a sulphuric acid bath which absorbs only the ammonia, with the

consequent formation of sulphate of ammonia. After leaving the acid saturator the gas is cooled again to permit of the absorption of the benzol products by the oil.

In the direct process, the tar is extracted from the gas without cooling by specially designed centrifugal apparatus or by a tar spray. The electrical method now being tested promises to equal either of these methods in efficiency.

In all three of the recovery processes the gas after leaving the benzol-washers is divided, and a certain proportion, usually 50% or less, sent back to heat the ovens, and the remainder may be available for any one of the many purposes for which gas of high heating value is applicable.

The total gas from a coke plant will show, after extraction of the benzol, from about 500 to 550 B.T.U. per cubic ft.; but if it is desired to get a gas of higher heating value for any purpose the ovens may be equipped with two collecting mains. The richer gas given off during the earlier part of the coking period goes into one main and the lean gas for the rest of the time into the second main. The two sections of the gas are kept separate through the by-product apparatus and the lean gas returned for heating the ovens, leaving a gas of over 650 B.T.U. or over for whatever purpose may be desired. These dual mains are usually installed on coke plants which sell their surplus gas to adjacent cities for lighting and heating.

To illustrate the value of the by-products, and also the loss sustained by their non-recovery, there is here presented a sort of balance sheet, taking a given quantity of coal and showing what can be obtained from it. The figures given may not necessarily be indicative of what results could be obtained from any coal, other than that referred to. The yield of by-products will vary slightly for different coals, and the yield of coke and quantity of gas will vary according to the volatile matter in the coal.

Starting with 1000 nett tons of a coal on which we have full data, the resulting product will be 670 tons of metallurgical coke, and about 40 tons of braize suitable for use under boilers or in domestic stoves or furnaces, and quite equal to anthracite

coal for such purposes; 3 tons ammonia, equal to 12 tons sulphate of ammonia or 14 tons nitrate of ammonia; 50 tons of tar, or about 9000 gallons; 1250 gallons benzol, 400 gallons toluol, 65 gallons xylol, 45 gallons heavy naphtha, 300 lb. naphthalene; 6,500,000 cubic ft. of surplus gas of 550 B.T.U. value.

At present it is practically impossible to place money values on either the coal or the various products, because the prices vary so much from time to time and also in different localities, and the same may be said regarding the cost of plant; but just prior to the war the writer prepared estimates on the cost of installing plants in two different localities in Canada, and in each case handsome returns on the investment were indicated. The matter goes further, however, than merely the immediate returns to the owners of a coke plant. There are also the important considerations of the conservation of our resources, and of other industries which can be developed by dealing further with the products obtained.

A few of the logical developments from the coking of the bituminous coal, from which now all the by-products are wasted, may be briefly mentioned.

Coke can entirely replace coal where such fuel is needed for domestic uses. It has also been used by one railway company for about fifteen years, replacing anthracite for use in locomotives.

At the present time all the coke used throughout the manufacturing districts of Ontario and Quebec, except by the Algoma Steel Co., is imported from the United States, where some of it is made without recovery of by-products, and the by-products made from the remainder are worked up in the United States and some of the products so made exported into Canada.

The distillation of tar usually constitutes a separate industry from the coke works, the main products from the distillation being creosote oils and pitch, with a small amount of benzol, toluol, naphtha, and carbolic acid.

There is undoubtedly a market for all the creosote oil which can be produced. The main use for it is as a wood pre-

servative. The Canadian railways have to a certain extent used creosoted ties, and doubtless in the near future they will all find that, with the increase in tie costs, they will have to creosote all ties to save expense of replacements. The same may be said for almost all kinds of timber work, particularly where exposed to the weather or water. A considerable quantity of creosote oil can be used also for recovery of the light oil from the gas. This is general European practice, though the American practice has been to use a petroleum oil. It can also be used for fuel for burning under boilers, or for direct combustion in Diesel engines.

A market for the pitch can be found in several ways. A great deal of it can be used to advantage as a binder in road making. A quantity can be used as a binder for briquetting non-coking coals. The remainder could be used as a boiler fuel, either in liquid form or by making a very hard pitch and using it in the same manner as pulverized coal.

The ammonia is usually shipped from the coke works in the form of sulphate of ammonium or as concentrated ammonia liquor. The chief use for sulphate of ammonium is, of course, as a fertilizer, and the ever increasing demand for chemical manures of all kinds is sufficient guarantee that there will always be a good market for this, the most important of the nitrogenous fertilizers.

The manufacture of ammonium nitrate at the present time is not only profitable, but must be increased to afford the quantity required for the manufacture of the needed explosives.

To treat adequately of benzol and other light oil products, and of their derivatives and uses, from light, heat, and power up to the finest drugs, perfumes, and dyes, would be impossible except in an exhaustive treatise. Benzol, either by itself or mixed with the toluol and naphtha, makes a most excellent motor fuel and will give at least 20% more power and mileage than gasoline. Prior to the war most of the motor vehicles in France employed benzol. When used for this purpose it is not necessary to refine it to nearly such a degree of purity as when it is produced to form the base of other products. A number of low-grade

explosives may be made by directly nitrating benzol; and practically all of the high explosives used in the present war are made from benzol or toluol with the addition of a quantity of ammonium nitrate.

Lyddite is practically pure picric acid, which is made by nitrating carbolic acid, which in turn is made by sulphonating benzol. Very large quantities of benzol have been used for this purpose since the war started.

Another high explosive is made by first producing aniline oil from benzol and then nitrating it. Aniline oil is the starting point also for the production of all the aniline dyes, as well as of a series of pharmaceutical products. Benzol, moreover, is employed to a considerable extent for enriching gas to increase its candle power; and is also used, both in its pure state and in the form of some of its manufactured compounds, in rubber manufacture.

All the toluol available at the present time is nitrated to make the high explosive tri-nitro-toluol. This is regarded as one of the safest high explosives as well as one of the most powerful. It may be used alone or with varying quantities of ammonium nitrate.

Dyes, drugs, and perfumes are also made from toluol.

The solvent naphtha, which usually includes the xylol, is commonly worked up in rubber and paint manufacture, although of late there has been a demand for a very pure grade of xylol to take the place of alcohol in certain industries.

Naphthalene is a solid crystalline substance which crystallizes out of the wash oil left after the first fractional distillation of the light oil, and is also crystallized out of some of the creosote oil in tar distillation works. The oil is extracted by centrifugal action or compression, and the naphthalene, after being given acid and caustic washes, is recrystallized or sublimed, resulting in a pure white crystal which is worked up into a great many different products, such as moth balls and other disinfectants and germ destroyers. It is also chlorinated, and a wax made from it which is used in electrical work. Finally, it is the base of the alazarine dyes.

The by-products of coal, therefore, are the foundation of innumerable industries, but such industries cannot be established without cheap power. This is furnished by the gas from the coal. As already stated, this gas may be used for lighting purposes. It may be burned under boilers or in the many types of industrial heating furnaces, or it may be made to generate power directly by being consumed in internal combustion engines. While some power plants report a relatively high power yield from the coal consumed, I think that it will be quite within the bounds of truth to say that, taking our manufacturing industries as a whole, we do not get as power more than 8% of the thermal value of the fuel burned. In gas engines 30% of the real value of the fuel is attainable, although from 22% to 25% is the more normal achievement.

ELECTRICAL PRECIPITATION OF TAR FOG[1]

By J. G. Davidson

The art of electrical precipitation, commonly called the Cottrell process, consists in the removal of solid or liquid suspended particles in the form of smoke, or fume, or fog, from moving currents of gases by means of electrostatic action. In the most usual type of treater built for the purpose, insulated wires are stretched along the diameter of the pipes, which may be twelve (12) inches in diameter and fifteen (15) feet long, through which the gas to be cleaned is passing, there being sufficient pipes to handle the total volume of gas. The wires are kept charged continuously, either positively or negatively, by high tension transformers and alternating current rectifiers to a potential almost as great as that which would cause sparks to pass from the wire to the pipe. Under these conditions, the silent or glow discharge from the wires electrifies the suspended particles in the gas, and the action of the field carries the particles to the pipes. If the material is dry dust it may then be shaken down. If it is composed of liquid or fog particles, the collected material will, of course, run off the pipes. It may safely be said that this method of cleaning gases is now generally accepted as the standard for the collection of valuable fumes from the stack gases of smelter and cement plants.

The idea underlying the work here outlined is that the process could be used in the collection of the by-products of distillation of wood and coal in such manner that the apparatus needed would be very much simpler than that demanded by present processes, and also that the collection of the various materials might be effected in such manner that the subsequent refining would be greatly simplified.

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[1]Summary of address given at the Annual Meeting of the Institute in March, 1918, the substance of which will be found with elaboration in a bulletin to be issued by the Advisory Council, Ottawa, and which may be had from the Council on application.

As the temperature of any natural hydro-carbon material, such as wood or coal, is raised, a point will be reached at which the material will begin to decompose into various new substances. As such destructive distillation continues to a final point in any ordinary operation, there will be left carbon and ash, for example, in the form of charcoal or coke, and there will have been driven off smoke and vapour-laden gases from which liquid products are collected in the various by-product processes. As the gas leaves the coal or wood in the oven, it is at a comparatively high temperature. At this point the smoke consists of fog particles of tarry material. If the temperature is very high these fog particles will consist essentially of pitch, while all the lighter oil by-products will be in the form of true vapours, indistinguishable at this point from the permanent gas. As the temperature is lowered these lighter oil vapours will condense and be absorbed in the fog particles of heavier tarry material already in suspension in the gas. The whole course of the by-product industry up to date has been determined by a remarkable physical property of this tar fog. It will not stick effectively to any baffling surface against which it may impinge unless the temperature of the gas is reduced to the neighbourhood of 35° Centigrade (100° Fahrenheit). The cooling of the gas to this temperature is a costly and often a very difficult process, and further, the baffling processes of collection which have been used to date have failed to effect the de-tarring of the gas effectively, except by very elaborate devices. In the cooling of the tar fog laden gases to the above temperatures water vapour always condenses, principally against the cooling surfaces, but in many cases as water fog in the body of the gas itself. The water thus collected will bring down with it in solution substances which are not soluble in tar, as for example, ammonia, acetic acid, and alcohol. The tar and the water fractions of the total condensate are thus collected simultaneously, and are always found to be capable of only incomplete separation by settling; the tar always contains a considerable portion of water in the form of emulsion, while the water fraction is darkened by finely divided or 'soluble' tar. Hence the refining processes consist in the complete separation of the tar and water

fractions as well as in the separation of their different proper constituents.

It has been shown that the Cottrell process may be used with admirable efficiency to remove the fog carried by gases from wood or coal or petroleum at any and all temperatures up to those which the writer has been able to obtain in the actual processes of the various industrial plants in which the experiments have been carried out. The outstanding problem to be solved was that of the insulation of the high potential wires. This difficulty was solved in an extended investigation carried out in the plants of the Vancouver and Tacoma Gas Companies. Special insulators of fused quartz, properly handled and placed in the treater chamber, are found to give satisfactory insulation with any and all of the different gases at different temperatures that have been tried. The simplicity and efficiency of the apparatus are surprising, one pipe twelve (12) inches in diameter and fifteen (15) feet long being sufficient to completely de-tar in the neighbourhood of a million cubic feet of gas per day, with a total consumption of electricity of two or three horse-power.

Horizontal Retort Oven Gases.—The electrical problems connected with the whole undertaking were worked out in experiments on these gases in the Vancouver and Tacoma Gas Plants. The different remaining series of experiments in the work were undertaken simply to demonstrate the various technical advantages to be derived from the use of the precipitation process in the collection of other by-products of distillation. The gas coming from the hydraulic main in these two plants reached the precipitation pipe at various temperatures up to a maximum of 160° F. Under these conditions some water always came down with the precipitated tar in the pipe. The cleaning was always found to be very much more complete than that effected by the ordinary tar extractors of the plant. Hence the ammonia water collected as a result of the subsequent cooling of the gas is always very much cleaner than that regularly collected, because of the absence of suspended or soluble tar.

Carburetted Water Gas.—Experiments were made in the Tacoma Gas Plant on gases taken directly from the stand-pipe between the super-heater and the wash-box. Because of the length of pipe needed to take the gas to the place where the treater pipe could be placed, the temperature in the latter could be raised to approximately only 500° F., the temperature in the stand-pipe itself being, of course, very much higher. At such temperatures tar fog particles could not contain any of the light or middle oils in solution; hence the collected material consisted of a soft, pitchy material containing the fixed carbon and the greater proportion of the heavy oils. The remaining oils and the water vapour carried in the gas condensed and collected later. All the electrical phenomena were much the same as in the previous work, and, in fact, these phenomena did not vary to any great extent during the whole course of the later work. This experiment demonstrated the feasibility of a fractional collection of the products of distillation at successively lowering temperatures.

Gas from Distillation of Wood. The apparatus was removed from Tacoma to the wood distillation plant on the grounds of the University of Washington at Seattle. This is a complete plant of semi-commercial size, designed to test the commercial possibilities of Northwest coniferous woods. The treater pipe was placed between the retort and the first condenser, and it was found that the smoke- and vapour-laden gases passed through during the greater portion of a run at a temperature slightly above the boiling point of water. Under such conditions the fog particles consisted of only the heavier tarry materials, and hence the material collected in the pipe consisted of anhydrous and rather heavy tar suitable for the market as a refined product. The gas passed from the treater pipe through the regular condensing and collecting system of the plant. The material here collected was composed of the light oil and aqueous materials which had passed through the pipe in the form of true vapour. It was found that the light oil would separate from the water fraction completely, and hence the latter was pale yellow instead of black in colour, as it is in the ordinary wood distillation process. It was thus demonstrated

that it is possible to save this very large quantity of tar, which is now ordinarily thrown away with the pyroligneous acid, in the distillation of soft woods. Also, where the pyroligneous acid is saved for its content of acetic acid and alcohol, it would be a very much more desirable product to handle if the heavy tar were collected as in the experiment. It is found that the light oil collected from experiments on Douglas fir mill waste compared favourably with ordinary pine oils for the flotation of ores.

Applications in Petroleum Distillation.—Various experiments were made in collecting by-products from coal in low temperature distillation processes. A description of this work may be found in the bulletin mentioned. The next significant work was carried on in the plant of the B.C. Refining Company at Port Moody. The apparatus was so installed that all the vapour from one of their big petroleum stills could be passed through the pipe. The work here was discontinued in the expectation that it would be carried forward immediately elsewhere, but nothing further has been done. It was found, however, that the precipitation apparatus would furnish a completely efficient dephlegmator, at least to the extent that all fog particles consisting of heavier substances than are desired at the temperature of the moment could be removed from the gas, and only the true vapours of the lighter oils warranted by this temperature could pass through for collection in the condenser. It was also expected that the total quantity of acid sludge which appears in the subsequent refining operations would be materially lessened by the removal of any asphaltic material being carried over in suspension in the vapour stream. This is the phase of this work which remains to be investigated; it did appear, however, that the greater portion of the acid sludge does not consist of asphaltic material carried over from the still, but is rather a new substance created by the chemical action of the acid on the oily materials present in the different collected fractions.

By-Product Coke Oven Gases.—At this stage of the work the Advisory Research Council of Canada undertook to finance a demonstration on coke oven gases at the plant of the Algoma

Steel Corporation at Sault Ste. Marie, Ontario. A by-pass was so arranged that a portion of the gas reaching the by-product house from the ovens could be passed through a treater pipe and thence into one of the regular condensers of the plant. It was not feasible to carry this gas through a complete unit of the plant; that is to say, after passing through the condenser the gas entered the main current of gas which had passed through the other condensers, and it could not be carried through separately into one of the saturators for the collection of its ammonia in the form of sulphate. The gas reached the treater pipe at a temperature of approximately 85° C. It was found that essentially all the ordinary tar carried by the gas was collected in the treater pipe; that is to say, at this temperature the tar fog particles were able to absorb essentially as much light oil from the gas as they would contain when cooled in the condenser to, say, 30° C. The ammonia liquor collected in the condenser was, as expected, practically clear, and furnished a very striking contrast to the dark-coloured liquid collected in the ordinary process. It may be taken as practically demonstrated that it must be feasible to build a by-product plant consisting of a small electrical precipitation plant for tar collection, exhausters, and sulphate 'saturators' into which the gas is passed without cooling in such a way that the water vapour is carried through without condensation to ammonia water. This would mean that the small and inexpensive electrical precipitation outfit would displace the condensers, tar extractors, reheaters, and all the apparatus needed in the handling of the ammonia water, all as carried out in the direct type of process plant. It is well known that the mains and ovens at this plant were temporarily in very leaky condition during the time of this experiment. This meant that the burning of the by-products in the ovens themselves and in the mains created considerable quantities of free carbon smoke which apparently is not found in gases from ovens running normally; in the latter case any cracking of the tar fog particles in the oven does not seem to be carried to the extent that only carbon particles are left. To those acquainted with the precipitation process it is well known that carbon smoke is, probably, the most difficult

material to handle. This problem led to practically all of the difficulties encountered in this experiment. In the opinion of the writer it is demonstrated that it is easily possible to use the process under such conditions, which may be assumed to be as bad as could ever be encountered in the industry.

The opinion is expressed that the possibilities indicated by the work outlined in this series of experiments are so great that the different branches of the distillation industry should lose no time in discovering if operation in continuous commercial practice would be as effective as the experiments indicate. If so, the outcome will be something in the nature of a revolution in the industries centring around the by-products of wood, coal, and petroleum.

The writer expresses cordial appreciation of the co-operation of all the staffs of the different plants where the work was carried out, as also for the financial and technical assistance given by the Western Precipitation Company of Los Angeles, California, and the Advisory Research Council of Canada.

THE GEOLOGIST AND THE DEVELOPMENT OF OUR OIL-FIELDS*

By M. Y. Williams

(Annual Meeting, Montreal, 1918)

Since the impetus given to oil prospecting by the high prices of petroleum products resulting from war demands, hundreds of oil geologists have been employed by American companies in the quest for oil. The Doherty interests are said in 1916 to have employed two hundred and fifty geologists, the work being placed under the direction of a chief geologist of wide experience. The State of Oklahoma has had hundreds of oil geologists at work within its borders during the past year. The question arises: Why the sudden recognition of the geologist in the oil development? The answer is that the recognition has not been so sudden as appears, but that the need for extensive development of the petroleum industry has caused the practice of the more advanced companies to be followed by the less advanced. Since I. C. White, in 1885, when a country school teacher in Pennsylvania, showed that he could predict oil pools from rock structure, recognition of the geological factors controlling oil accumulation and consequently recognition of the aid given by the geologist in oil development has grown rapidly from year to year.

What other science should be able to make the same contribution to oil development as geology? The sequence of formations, rock porosity, rock structure: these are all vital factors in oil occurrence. Why then any need to vindicate the work of the oil geologist? Firstly, because of the diminishing but inherent distrust on the part of the practical man for the work of the scientist; and secondly, because of the limitations of geological accomplishment, especially in the early stages of the development of most oil-fields. Where rock outcrops are scarce, the geologist can work effectively only hand in hand with the driller. After all, is this not the solution of the problem of the

*By permission of the Geological Survey, Ottawa.

'practical man' versus the 'scientist'? The two must work hand in hand; they must supplement each other.

Simply stated, the factors causing oil to accumulate in inverted rock basins, consisting of domes, anticlines, monoclines, etc., are as follows: Gas, oil, and salt water usually are found together in oil-fields, their specific gravity varying from least to greatest in the order named. Where these fluids fill a doming, porous, rock stratum overlain by an impervious stratum, the gas ascends to the top, the oil occupies a middle position, and the salt water fills the lower areas. It is obvious that oil and gas can be obtained only by penetrating the upper portion of the dome structure. This as a theory was advanced by T. Sterry Hunt in 1861 and demonstrated by I. C. White in 1885, and has been shown over and over again to represent the actual conditions in many oil-fields. Where water is absent, however, oil and gas gravitate toward the synclines and, though lacking the impelling forces furnished by hydrostatic head, may form considerable accumulations. In some fields the oil-bearing strata differ much in porosity from place to place, and the porous areas have accumulated the oil independently of structure. This is the exception which proves the rule. The simple control of oil accumulation in a folded rock area is replaced in faulted areas by various conditions in which inverted rock basins are formed by the juxtaposition of fault-blocks.

Summing up: Oil may be expected to occur, first, in inverted rock basins (or on the limbs of basins, monoclines, terraces, etc.) if water is present; second, in normal rock basins such as synclines, if water is absent; and third, independently of structure where rock porosity is varying to a great degree. For the purposes of this paper, the many exceptions to the above rules met in the development of oil-fields may be disregarded, since structure is after all the most dependable, and the principal controlling factor in oil accumulation.

Knowing the conditions, the problem of rock structure is to the fore, and this is a geological problem. In undeveloped areas, the geologist can be of most effective service by working out the distribution and structure of the geological formations

present in as great details as outcrops will permit. As soon as drilling has commenced, a study of the underground geology as gained from the well drillings claims special attention. The most satisfactory way of compiling records obtained from drilling is to make a structure contour map of the top of the oil-bearing formation, or of some easily recognized horizon, such as a bed of black shale, a coal seam, or a well-marked sandstone bed. The elevations of the tops of the wells are first determined and referred to some known datum plane, preferably the sea level. From the well records, the elevations of the chosen horizon, where penetrated by the drill, are next determined in reference to the datum plane, and using these points as control, equally spaced contour lines are drawn which will indicate the structure of the formation in the same way that a contour map of the surface of the land shows the shape of the land forms. Rock formations met in oil exploration are, however, generally undissected and consequently do not show the variety and contrast of shape which is the result of stream and other erosion on land surfaces. Thus as drilling proceeds the rock structure is worked out, and new wells may intelligently be located in reference to wells already drilled.

Since oil was struck in Alberta in 1913, the Geological Survey of Canada has been doing in that province the kind of work outlined above. D. B. Dowling has been in charge and has been assisted by Mr. Slipper, who has been resident in the field most of the time.

In southwestern Ontario, until this past season, the assistance rendered operators by the Geological Survey has taken the form of descriptive geology, broad indications of structure, and the accumulation by the Water and Borings Division, under E. D. Ingall, of such records of wells as could be obtained at the office, by correspondence.

In the *Geology of Canada*, 1863 (p. 379) the Onondaga (Corniferous) limestone is mentioned as the source of the oil discovered at Enniskillen and Tillsonburg. The anticlinal theory of oil accumulation is also clearly stated. A general statement is made of the supposed location of the Cincinnati

anticline, and other evident structure is mentioned in different places in the report. Some of the older men in the Bothwell field relate Sir William Logan's prediction of the finding of oil in the Bothwell region, and the personal encouragement given to oil development by members of the Geological Survey was doubtless of real service. Later on, however, little was done to assist in the development of the oil fields, and what scientific work was carried on was due to such men as Eugene Coste, Frank J. Carman, and Dr. C. O. Fairbanks.

This past season, on the initiative of the Deputy Minister of Mines, Mr. R. G. McConnell, the writer started the work of assembling and correlating information available in the oil-fields, with the purpose of finding suitable localities for further prospecting.

The first field studied was the area in the vicinity of Milton, Halton Co., Ont., where some oil has been struck in a well drilled into the Trenton limestone. This area promised to be interesting, since the proximity of the Niagara escarpment made it possible to attempt to work out the geological structure at the surface. A difficulty common in such work, however, was met at the outset, viz., the gathering of accurate information relating to the wells that had been drilled in the vicinity. With the assistance of H. F. Slater, of Toronto, probably all the available information was assembled. The levels of the tops of the wells were carefully determined and a structure-contour map of the top of the Trenton limestone was constructed. (See diagram.) Information proved to be deficient, however, as will be seen from the accompanying diagram, at a critical point. Apparently no record was kept by the company which drilled the McCannell well on lot 1, con. II, Esquesing township, and drilling was stopped at the top of the Trenton. Thus money was more than wasted, for though properly located to test the higher portion of the dome, the well was not sunk deep enough to prove anything, and its record was not kept to help in working out the structure of the field. However, no water has been reported from the Trenton limestone of this area, and it is possible that oil might be obtained by drilling on the lower structure. The wells drilled

south and west of the oil well, though on lower structure, did not produce oil, but on the other hand both the producing gas wells are on lower structure, and wells near these but away from the dome might strike oil. The oil and gas found do not occur at the same depth in the formation, however, and it is, consequently, to be feared that rock porosity rather than structure controls the occurrence of oil.

The results obtained from the attempt to work out structure from the outcrops along the Niagara escarpment were inconclusive, as outcrops of identifiable beds are so far apart that little more was ascertained than that the formation rises to the north.

While the work was being done in the Milton field, the long recognized Rockwood anticline was definitely examined and described[1] with the result that 40,000 acres of land in this vicinity have been leased and the Trenton of the area is being prospected.

The second problem undertaken was the working out of the structure of the Onondaga (Corniferous) limestone in the vicinity of Bothwell and Thamesville. The Onondaga is here the oil producing formation. D. W. Williams, geologist to the Dominion Gas Co. of Buffalo, had already worked out the general structure of the Onondaga from Bothwell southwest beyond the Essex county boundary, and although his information was not available to the public, he generously placed it at the disposal of the author for comparative use. The Bothwell field itself had been carefully studied by F. J. Carman, who is mainly responsible for its successful development, by Dr. C. O. Fairbanks, A. M. McQueen, and others; but, as no structure map was ever made, there was no permanent record of this work other than that contained in the notes of various men. Another source of information which is rapidly passing beyond our grasp is that to be found in the memory of some of the older men who took part in the early oil development. As example of a man of this class is Mr. A. C. Sussex, of Bothwell, who furnished much very valuable information relating to the early drilling done in the Bothwell field.

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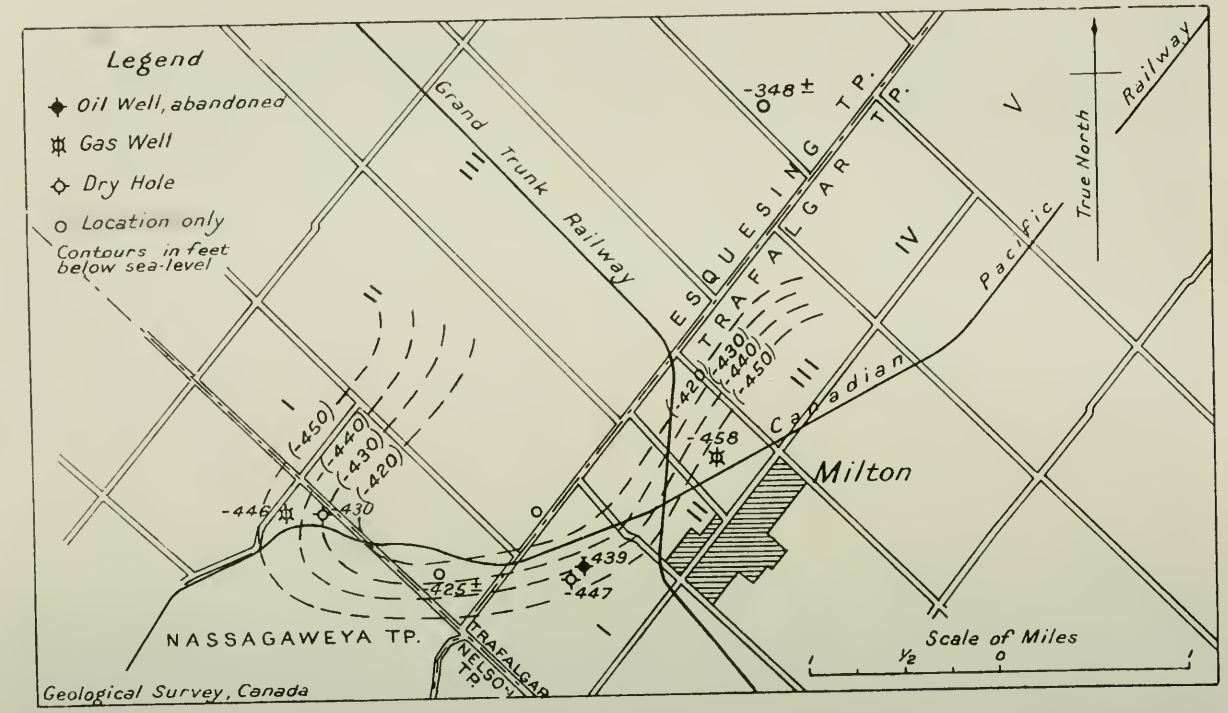
[1] See *Canadian Mining Journal*, July 15, 1917, p. 290.



Structure of the top of the Trenton formation near Milton, Ont The broken lines indicate approximate contours. Contour intervals are 10 feet; elevations are below sea level.

Thanks to the kindly co-operation of all concerned, much information was assembled relating to Bothwell and vicinity. The elevations of the tops of the various wells from which logs were obtained were determined, and the accompanying structure map is the result. This map has been inspected by three of the oil men best informed on the Bothwell region and is said to represent their knowledge of the field very correctly.

The evident purpose of such work is to suggest undiscovered oil pools, or favourable areas for prospecting. It will be seen that the area extending from one-and-one-half to four miles east of Cashmere offers promise of another dome in line with the Bothwell anticline. A number of other observations might be made on the structure of Bothwell-Thamesville region, the most important perhaps being that, of all the domes represented, only the highest in the field, viz., those near Bothwell, have been continuous producers of oil for a long period of time. F. J. Carman's opinion appears to be sustained—that the oil siphons from the lower domes into the higher ones, leaving only crevice oil and 'top show' oil in the lower areas. The occurrence of oil in domes is well illustrated in the case of the Bothwell field, and the occurrence of many dry holes near good oil pools is clearly explained.

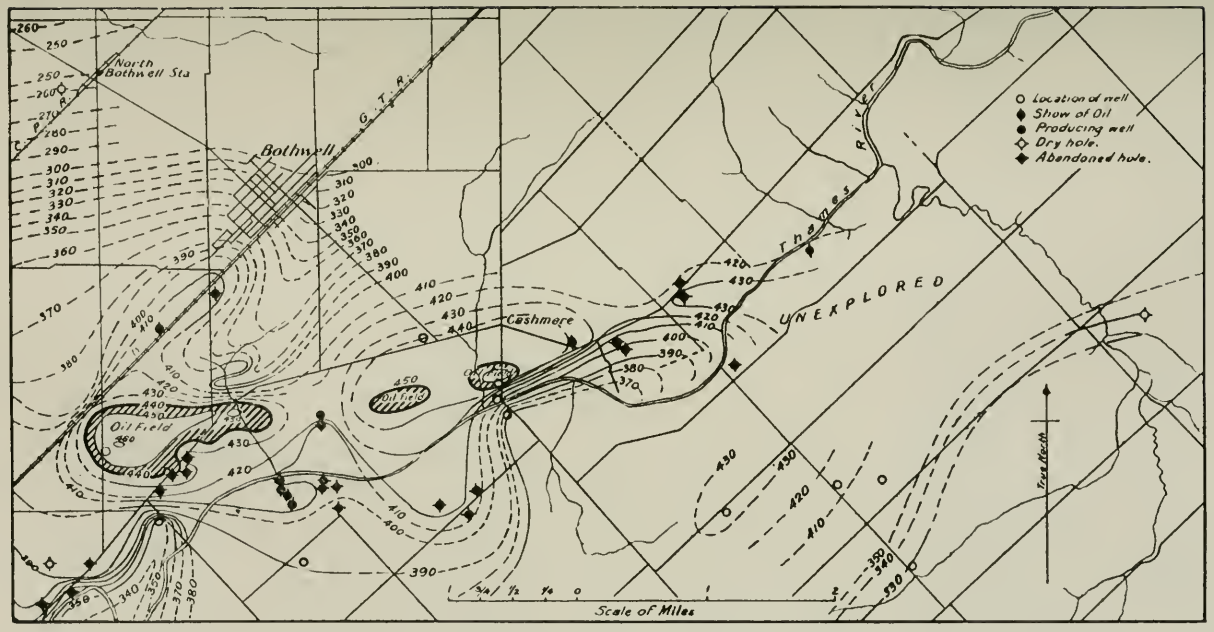
After completing the work in the Bothwell-Thamesville vicinity, an investigation in Dover township, Kent Co., and the vicinity was undertaken in conjunction with the drilling operations of the Union Natural Gas and the United Development companies. The high-pressure gas struck in a well drilled into the Trenton limestone on lot 3, con. 3, West Dover, by the Union Natural Gas Company last spring, attracted widespread attention, and eight other wells were started during the summer and two more in the autumn. This is by far the most systematic as well as the most expensive attempt yet made to explore the Trenton in southwestern Ontario, and the co-operation of the Geological Survey was welcomed by the operating companies. Consequently, six weeks were spent in this region studying the well samples as they were taken, levelling the tops of wells, etc. Since the close of the field season, the companies have kindly

supplemented the information gained by sending additional samples and records. At present, five wells located within a radius of two miles of the 'discovery' well have been sunk into the Trenton, but no commercial quantity of gas has been found. Meanwhile, the 'discovery' well, which produced small quantities of light oil from the start, is gradually changing to a profitable oil well.

No water has been found in the Trenton of Dover township, and the 'discovery' well is on the lowest structure so far found in the field. Other wells sunk on the syncline, however, are unproductive, and the natural conclusion is that porosity rather than structure controls the oil and gas occurrence. A well located north of the 'discovery' well and presumably lower in the syncline would indicate whether through lack of hydrostatic pressure the oil and gas occupy a basin structure.

Much interesting geological information has been obtained from the study of the Dover wells, the most important results being the determining of the structure of the field so far tested, and the proving of the sub-parallelism of the lower and higher formations. Ohio geologists have concluded that the structure indicated at the surface of the oil-fields extends downwards to the Trenton, but it remained to be shown whether this held true also for Ontario. In the six wells which have been sunk to the Trenton in Dover an approximation to parallelism in the formations is present from top to bottom, excepting in the case of the only well which penetrates salt (a bed 125 feet thick). The salina formation in this case is materially thicker than elsewhere, and the overlying formations are consequently higher, the dip in the Onondaga between this and nearby wells being in some cases the reverse of that in the Trenton. The conclusion is forced upon us that at least where salt deposits (and probably the same holds for gypsum deposits) occur the structure in the Devonian does not necessarily extend downward into the Trenton. From the Silurian downward, the formations in all the wells are nearly parallel.

The statement of some of the results of the past season's work is given to illustrate the problems that remain to be solved



Structure of the top of the Corniferous (Delaware) limestone showing the Bothwell oil-domes. Structure contours where uncertain are indicated by broken lines. Contour intervals are 10 feet; elevations are above sea level.

in southwestern Ontario. A truly ponderous mass of information is available to the investigator, but this is diminishing in quantity and value from year to year. It is not expected that a new Oil Springs or a new Petrolia will be found, but it is possible to direct drillers to the most likely areas for prospecting, and to warn them from unlikely fields. If the statement, credited to the superintendent of one large oil company, that 50% of the dry holes were avoided by the employment of geologists, holds good, the importance of the geologist in the development of our oil-fields is manifest.

THE SMELTING AND REFINING OF SILVER ORE FROM THE COBALT AREA; AND THE PRODUCTION AND USES OF STELLITE

By Sidney B. Wright

The ore received at the works of the Deloro Smelting and Refining Co., Ltd., from the shippers in the Cobalt and Gowganda districts, consists of high and low grade silver-cobalt ore in lump form, jig and table concentrate, and ore residues such as those produced by the Nipissing Mining Company and the Mining Corporation.

Sampling.—For sampling purposes the ore is ball-milled to about a 20-mesh product, a 14% cut being drawn by a Snyder disc machine as the bulk sample. After a second Snyder cut, the sample, now constituting about 2% of the original ore, is transferred to the sampling floor, where after thorough mixing it is coned and quartered into two samples which are then quartered down separately.

Reserve samples of these original pulps are sealed and retained for umpire purposes, until settlement has been made for the shipment.

The control samples are ground to pass a 100-mesh screen, scales being separated as usual for assay purposes.

The requisite number of assay samples is drawn for the shipper, smelter, and independent assayer; the certificate of the last governs in settlement for the shipment.

Metallics or nuggets are removed from the ball-mill after the carload or lot has been crushed, and are melted down to base bullion in an oil-fired crucible furnace. The silver content, as shown by assay, is added to the total silver contained in the milled pulp, and settlement made accordingly.

Smelting.—After the ore is sampled it is transferred to bins, from which it is charged to the blast furnace. The charge is so calculated as to furnish a practically neutral slag, and, on account of the large quantity of fines present, the furnace is run generally at a blast pressure of only 6 to 8 oz. It was considered probable that by briquetting the fines the capacity of

the furnace would be increased, but the test runs made on these lines have not yet produced the desired metallurgical results. The ore, and reverts from other sections of the plant, are therefore mixed wet and charged to the furnace in the form of a stiff mortar; this sinters fairly well before the smelting zone is reached, the actual flue dust produced amounting to about 6% of the ore and slimes charged. The products of the smelting operation are speiss, from which a quantity of base silver is liquated in the case of high grade runs, slag, and arsenic fume, which is collected in bag houses of the regular type.

Desilverizing the Speiss.—The speiss produced contains approximately:—

Co	22—25	per cent.
Ni	16—18	" "
As	25	" "
Fe	18	" "
S	7	" "
Cu	1	" "
Ag	1000 to 1200 oz.	per ton.

This speiss product is ground in a ball mill until the whole passes a screen with 40 meshes to the inch. The ground material is then roasted until it contains only 10% of arsenic. The roasting is done in a furnace of the reverberatory type which is equipped with mechanical rabbles having water-cooled arms. The roasted speiss is then mixed with salt and given a chloridizing roast in a Bruckner cylinder.

The chloridized speiss is washed with water and then agitated for one hour with a cyanide solution containing the equivalent of 20 lb. KCN per ton. The silver is precipitated from the solutions by means of aluminium dust, one part of which deposits about eight parts of silver in our practice. It is interesting to note that the cyanide actually regenerated in this precipitation is practically equal to the theoretical quantity formerly present in the double silver salt.

The precipitate now goes to the silver refinery and the desilverized speiss residue to the oxide plant.

Silver Refining.—The base silver, liquated in the form of bottoms from pots of speiss, averages about 800 fine, the balance consisting of arsenic and antimony, with some cobalt, nickel, iron, copper and bismuth.

This bullion is refined by melting it in an oil-fired Schwartz furnace, which is equipped as a small converter. As soon as the charge is in a molten state the furnace is tilted backwards into blowing position and the metal is blown for about three hours. During the first half-hour of this period the oil is shut off from the burner, the heat of the reaction being sufficient to keep the metal molten for that length of time. After a short further heating up the charge is poured into ingot moulds.

The silver bullion thus obtained averages from 990-995 fine, and is brought up to commercial grade (996 and better) by remelting with silver precipitate from the cyanide plant; this operation is performed in a second Schwartz furnace. The gases from these furnaces are drawn through coolers and passed to a small bag house. The fume is rich in silver, carrying about 800 oz. per ton, and consists essentially of arsenious oxide with some antimony and bismuth oxides. All bullion slags and this fume are eventually recharged to the blast furnace.

The gases from the blast furnace, the roasters and chloridizers are drawn through flues and coolers before reaching the bag houses which collect the crude arsenious oxide. The temperature of the gases entering the bag houses is regulated at a maximum of 250° F. by means of a thermostat operating a damper in the main flue; when the temperature rises to 250° F. cool air is immediately drawn in, reducing the temperature.

Refining the Crude Arsenic.—The crude arsenic that is collected in the bag houses is sent to refining furnaces, which are coke-fired reverberatory hearths. The arsenious oxide that is formed is volatilized and condensed in chambers that are emptied at intervals of ten to fourteen days. The product from these chambers is pulverized and packed in barrels by means of a Raymond Pulverizer, a system that certainly deserves the admiration and gratitude of the packer and his employer when handling such materials as arsenious oxide.

The clinker or slag drawn from the refining hearth contains all the silver that was formerly present in the crude arsenic; this slag goes back to the blast furnace.

Oxide Plant.—It is necessary now to return to the desilverized speiss residues which contain the cobalt and nickel values of the ore. The metals in this material are present principally in the form of oxides, so the first treatment is that of sulphatizing in order to render the cobalt and nickel soluble as sulphates. The sulphatized speiss is charged to tanks in which the mass is agitated with hot water and the sulphates dissolved. The liquors thus obtained are then freed from copper and iron before being passed to the precipitation tanks.

The cobalt and nickel are separated by fractional precipitation with hypochlorite solutions, the nickel being finally precipitated as hydroxide by means of milk of lime.

The hydroxides of cobalt and nickel thus obtained are filter-pressed, washed and dried, after which treatment the oxides are either pulverized and packed for the market, or are transferred to the Metals Department for reduction to the metallic state.

Metals Department.—For the purpose of reducing the oxides they are mixed with charcoal and reduced to rough metal in oil-fired furnaces. After separation from excess carbon by means of a magnetic separator, the rough metal is melted in electric furnaces and converted into shot form by pouring into water.

The 50 K.W. electric furnaces used are of the single-phase, top and bottom electrode type, lined with magnesite, and have a capacity of 100 lb. of cobalt or nickel metal per hour.

PART II

THE PRODUCTION AND USES OF STELLITE

In a paper contributed last year to the American Institute of Metals, Elwood Haynes, the inventor of Stellite, gave some very interesting information regarding his original work on these

alloys. He mentions that in 1887 he made some experiments with a view to obtaining an alloy which would resist the oxidizing influences of the atmosphere and at the same time take a good cutting edge.

Alloys containing copper were found unpromising. In 1892, an alloy of nickel and tungsten was made, containing about 30% of the latter metal, but it was found to tarnish slowly in the laboratory atmosphere. In 1899 an alloy of nickel and chromium was made, containing 10% or 12% chromium, and later alloys of these two metals were produced containing up to 50% chromium. Shortly after this, an alloy of cobalt and chromium was made. It was found that in point of hardness, resistance to attack by nitric acid, malleability when hot, and general properties, these alloys were so promising, having regard to what was required of them, that in 1907 patents were taken out on both the nickel-chromium and the cobalt-chromium alloys. A paper describing these alloys was read before the American Chemical Society in July, 1910. The cobalt-chromium alloys were found to be workable to a limited extent at a bright red heat, and were made up into table-knife blades, pocket-knife blades and various other forms.

Mr. Haynes gave the name 'Stellite' (from *stella*, a star) to these alloys on account of the fact that when polished they retain their lustre indefinitely.

It was found, however, that for the manufacture of cutlery these alloys were somewhat too difficult to work, and, in the meantime, Mr. Haynes had experimented on the addition of tungsten and molybdenum to the alloy. He found that the introduction of either of these metals increased the hardness of the alloy very greatly and, at the same time, made it less malleable and more brittle.

By introducing from 8% to 20% of tungsten, ternary alloys were made, and their hardness was so great that they would scratch quartz. Lathe tools made of these alloys were then tested in the machine shop, and the remarkable results obtained led rapidly to the adoption of Stellite tools in many shops. Patents covering the ternary alloys were granted in 1913.

Manufacture.—The manufacture of Stellite on a commercial scale in Canada was commenced in Deloro in December, 1915. The furnace used was a 25-kilowatt, arc type, single phase, with two top electrodes. This was later changed to top and bottom connections, the metal bath forming the bottom contact. The capacity of this furnace was about 45 lb. of Stellite per hour.

This melting capacity proved sufficient until August, 1916, when it was found necessary to install two larger furnaces in order to meet the increasing demand for the alloy.

Two 50-kilowatt tilting furnaces of practically the same type as the original furnace were installed in September, 1916. These are lined with kieselguhr to the thickness of one and a half inches next to the shell, then four and a half inches of firebrick and an inner tamped magnesite and tar lining of about seven inches thickness. The roof is of special firebrick tile made to specifications. The electrode connections are water-cooled.

The capacity of each furnace is approximately 100 lb. per hour, and generally only one furnace is operated at a time.

Operation.—The requisite quantities of cobalt, chromium, and tungsten metals are mixed and charged to the furnace, the arc being started using current at 50 volts. When the furnace is running smoothly, the pressure is increased to 100 volts, the amperage averaging about 80. The circuit breaker is set to trip at 105 amperes.

The molten metal, when at a temperature of approximately 1550° C., is poured into graphite moulds set on a revolving stand at a convenient distance from the furnace. When cool the bars or shapes are trimmed, the ends cut off, and then ground on alundum and carborundum wheels.

The bars are cut to length by means of Armstrong cutting-off machines; and it is interesting to see the steel disc of this machine, which revolves at about 3000 R.P.M., cut a clean groove about 1-16″ wide in its master Stellite. By nicking on two or three sides of the bar in this way, a fairly clean break

is readily obtained by placing the bar on a concave anvil or in a vice and then giving a blow with a hammer.

A sample bar representing each ladle of metal poured is set aside for lathe test.

Each lot also passes through three inspections before being passed for entry into the stock-room and thence to the market.

Stellite does not flow so readily as iron or steel; even when thoroughly heated for pouring it appears to be of a thicker consistency than many other metals, and for this reason the proportion of poor casts is large.

It is also more likely to contain blow-holes, which in most cases are probably due to air being trapped during the pouring into the moulds. The presence of such holes does not by any means impair the quality of the metal itself, but if excessive in size may cause the tool to be too weak to stand the strain, and so make it break at the blow-hole. In most cases the tool can be reground and used up in spite of such a break.

Stellite for tool metal purposes is made in three grades of hardness. *No. 1* is the mildest and toughest, and is used mostly on low carbon steels. *No. 2* is harder than No. 1, and is suitable for turning steel from 30 to 100 point carbon and cast iron of moderate hardness. This is the general purpose grade and is used in practically all shell shops, where the adoption of Stellite has undoubtedly been the means of speeding up production to a very marked extent.

No. 3 is much harder than either of the two other grades, and is specially adapted to turning hard or soft cast iron, hard bronze, and other metals or alloys.

Recently, Mr. Haynes was asked to furnish a special grade of Stellite for use in boring the cylinders of the Liberty motor now used in aeroplanes. This he succeeded in doing, and, as this No. 4 grade has apparently even more wonderful cutting properties than the others for special purposes, it will be produced before long at Deloro for the Canadian and European market. It is said that the machining of high-speed tool steel can be performed with this No. 4 Stellite.

The rapid developments in the use of Stellite on this continent and in Europe have, to a certain extent, interfered with the carrying out of research work on these alloys to the extent desired.

Uses.—The variety of uses to which Stellite is being put is increasing steadily—thus it now enters largely in the manufacture of many makes of automobiles. In connection with the production of 6-inch and 75-mm. shells in Canada production was accelerated to a surprising degree by the use of Stellite tools. As an example of this it may be permissible to submit the following figures furnished by a Canadian shop:—On 6-inch shells, average depth of cut ½ inch, the average speed with high-speed steel tools was 45 feet, the average feed $\frac{1}{32}$ of an inch, and the production per hour 5 shells. Using Stellite tools, the average speed was 55 to 65 feet, the average feed $\frac{5}{32}$ to ⅛ of an inch, and the production per hour 7½ shells. On the rough turning of 75 mm. shells the production, using high-speed tool steel, per machine per hour was 17 shells; with Stellite tools the production increased to 23 shells per machine per hour. Stellite has also been employed with success at mines in the Porcupine district in facing off pump liners, which high-speed steel had failed to do effectively. The use of Stellite in the form of welded tools is also developing rapidly. The Stellite tips are usually welded to carbon steel shanks; and various tools are made, with the aid of the acetylene torch, by building up Stellite tips or edges on steel bosses or shanks.

During the past year much time and money has been devoted to experimentation along the lines originally contemplated, namely, the application of Stellite to the manufacture of cutlery, surgical instruments, etc. The following articles have been made to a greater or less extent: pocket-knife blades, table-knife blades, surgical instruments, spatulas, dental instruments, evaporating dishes, annealing dishes, ornamental work, valves, plumbing fixtures, pens, and combs.

By modifying the composition of the alloy, a form of Stellite that is practically malleable has been produced, and most of the above-mentioned articles have been made of this class of

material. Table and pocket knives, surgical and dental instruments have already given splendid results as regards their mechanical properties, and in addition have demonstrated conclusively that the alloy is practically unaffected by all sterilizing and similar solutions, including nitric acid. Spatulas of this material are very satisfactory for use in the chemical laboratory, but they must not be exposed to hydrochloric, hydrofluoric, or sulphuric acids. They are, however, unaffected by nitric acid, or by ordinary solutions of the organic acids, or by boiling solutions of the caustic alkalies.

DISCUSSION

MR. A. R. WHITMAN: Mr. Wright spoke of the hardness of Stellite as compared with that of quartz. I would like to ask whether the possibility has been considered of using Stellite in place of diamonds in a diamond drill.

MR. WRIGHT: Only recently a man from one of the mining districts called at our Toronto office and obtained some Stellite in order to determine that very point. He stated that he intended to cut small pieces and to set them in his drill-bit in place of the diamonds. We have not heard yet as to the result of the experiment. I would not care to affirm that it is very likely to be successful, for Stellite can be ground by abrasion, and for that reason it is difficult to say whether it could be used to replace diamonds for drilling.

MR. G. M. COLVOCORESSES: What is the chemical composition of Stellite?

MR. WRIGHT: The percentages range—cobalt from 50 to 60%; chromium from 30 to 40%; tungsten from 8 to 20%.

MR. COLVOCORESSES: Is there no iron in it?

MR. WRIGHT: Practically none—only a very small quantity contained by the metals used in making the alloy.

MR. C. A. O'CONNELL: What is the actual hardness of Stellite ?

MR. WRIGHT: I cannot give the Brinnell number, but our own tests with the scleroscope indicate that the hardest tool steel records 80 as against 90 for Stellite under the same conditions. On account of its hardness and structure, Stellite is comparatively brittle, and therefore requires extra support in the tool-holder.

MR. W. K. MCNEILL: How do you sample and analyse Stellite ?

MR. WRIGHT: Both of these operations are very difficult. A piece is broken off the bar for sample purposes, and, in order to reduce it to a sufficiently fine state for analysis, we have to grind it down in a mortar made of Stellite. By bringing it down to as near a −100 mesh product as possible the chemist is able to dissolve the metals fairly well by prolonged boiling with hydrochloric acid. Any insoluble residue is fused with potassium bi-sulphate or sodium carbonate. The chemist in any case has his own trouble, in dealing with Stellite, as you will readily appreciate.

MR. A. A. COLE: Did not the Sheffield cutlers rename Stellite ?

MR. WRIGHT: When the original binary alloys were being tested out for cutlery purposes some Stellite was sent to Sheffield to be made up into table knives, etc. The cutlers had great difficulty in doing anything with it, as Stellite requires entirely different methods of handling from those used in the case of steel. One of the cutlers tried to drill a hole in the tang of a knife and was much surprised when he found it was impossible to make any impression upon it. A Sheffield professor who had undertaken to analyse some Stellite told those who were interested that after struggling with it for some time he had come to the conclusion that a more appropriate name for the alloy would be 'Hellite.'

MINING IN NORTHERN MANITOBA

By E. L. Bruce

(Annual Meeting, Montreal, 1918)

Two areas in northern Manitoba, both in the same belt of basic pre-Cambrian rocks, have been for the past three or four years attracting the attention of mining men. The most westerly of these, the Schist lake or Flinflon district, situated near the western boundary of the province, and approximately 125 miles northwest of lake Winnipeg, produced during the past year a considerable amount of high-grade chalcopyrite. Now that the Hudson's Bay Railway has been completed to a point north of the Saskatchewan river, this district may be reached by rail to the Pas, and thence by steamer up the river to the head of Sturgeon lake. Thence a waggon-road now leads to Athapapuskow lake, or the journey may be continued in canoes up the Sturgeon and Goose rivers to Athapapuskow, across that lake, and up Schist creek to Schist lake, upon which the Mandy mine is situated.

History of District

Although to the mining fraternity a new country, this area northwest of lake Winnipeg is by no means an unvisited region. Its waterways formed travel routes for the early explorers while Canada was still under French rule. The first permanent establishment at Cumberland House was made by Samuel Hearne in 1776 immediately after his return from the famous journey to the Coppermine. There seems to be no record of the route he followed from the Bay to Cumberland, but it is likely that he crossed the mineral belt. The Frobishers, Alexander Henry, Pond, and Fidler all travelled the waterways between Beaver and Herb lakes. David Thompson had a house on Reed lake and another on the Cranberry lakes; and between the year 1800 and 1810 he crossed and recrossed lake Athapapuskow many times. These men were chiefly interested in the Indian trade, and they had not the time nor were they encouraged to

attempt the development of the natural resources of the country other than the fur. Only in recent times, largely as a result of the work of McInnes, Dowling, and Tyrrell, was attention drawn to the possibilities here in respect of the occurrence of deposits of valuable minerals. The first prospectors, influenced by the discovery of gold at Porcupine, confined their attention mainly to quartz veins; and for a time during 1914 there seemed a possibility of the western part of the greenstone belt becoming a gold-producing area. The development of these prospects was, however, discontinued, the veins being small, irregular in point of size and values, and capital was unavailable.

Before the construction of the Hudson's Bay railway was commenced, the distance of this district from railway connections made it difficult and inadvisable to explore except along the main canoe routes, and up to 1915 the country between Beaver lake and lake Athapapuskow was almost entirely unknown. Prospectors finally began to work eastward from Beaver lake, and in 1915 a fairly complete map of that district was completed. The first discovery of a large body of sulphides was made at Flinflon lake during the summer of 1915 by the Mosher-Creighton party, guided by an Indian whose hunting grounds lay around Flinflon and Schist lakes. During the latter part of the summer they trenched the deposit as far as the lake level would permit, but news of the discovery was not allowed to reach the outside until late in the autumn. The Mandy deposit at Schist lake was discovered just before the lake froze. Diamond drilling was begun during the winter on both bodies, and was continued during the summer of 1916 at the Mandy. At Flinflon, which was under option to the Jackling-Hayden-Stone interests, exploration was discontinued in July and the option given up. At the Mandy, the drills having proved the existence of a large body of high-grade copper ore, the management decided to open-cut the deposit, and 3,625 tons of ore averaging 19% to 20% copper were taken out and hauled over the lakes and winter roads to Sturgeon lake. During the summer of 1917, 3,500 tons of this ore were taken by barges and tugs down the Saskatchewan river and shipped to the smelter at Trail, B.C. Owing to the low water in Cumberland lake, which pre-

vented barges getting through during October, 125 tons still remained at Sturgeon lake. While ore was being taken out, equipment was brought in and an up-to-date mining plant installed. This consists of a 125-horsepower boiler, 7-drill compressor and a hoist. A portable saw-mill was also brought in to saw lumber for the compressor building and camp. Besides this equipment the company operates a stern-wheel steamer and four barges on Schist lake, a 60-ton tug and two barges on Athapapuskow, and four barges, handled by the Ross Navigation Company, on the Saskatchewan. After the lakes began to break up last spring the sinking of a vertical shaft was started. By August, a depth of 100 feet was reached, a station cut, and a crosscut driven 50 feet to the ore. The open-cut was timbered to prevent caving, and underground mining was begun. In the interval, until the lake froze, 2,100 tons of ore had been hoisted from this shaft. During the winter of 1917-18 sinking for a further 100 feet was in progress to admit of mining from two levels, and a contract for 7,500 tons of ore was closed. The ore sent to the smelter during 1917 carried about 19% of copper as well as a little gold, hence the value of the output was approximately $325,000. The ore that will be produced during this year will probably be of equally high grade, and the value of the 1918 production should be well over a half million dollars.

DIFFICULTIES OF TRANSPORTATION

The magnitude of the work can hardly be appreciated without an understanding of the character of the country; hence a brief review of the topographic features is desirable. The Saskatchewan river from Cumberland lake to lake Winnipeg flows through a flat clay-covered country underlain by dolomite. The main channel is separated by low willow-covered banks from broad, shallow lakes acting as equalizing reservoirs into which water flows in periods of flood and from which it is fed out as the river falls. Where there are no such lakes the bank falls inland to broad muskegs that are but little above river-level. Those in high water are flooded for some distance from the river. Frequently there are minor changes in the course of

the river and occasionally a great shift. Some years ago the river broke across into the Torch river and now flows into Cumberland lake instead of through its former channel, which is almost dry. On reaching the quiet waters of Cumberland the silt carried by the river is deposited, and the lake has been gradually filled up so that now the shallow-draft steamers have much difficulty in getting out into the open lake in low water. Possibly the time is approaching when another change of drainage will take place. The new channel most likely to be occupied is a high-water connection with the Carrot river, known as the Sipanok channel. Should this occur, transportation of the ore by boat farther than Cumberland House may be impossible.

North of the dolomite, the country has the typical rugged, broken surface of the Pre-Cambrian, but the differences of elevation are not great. Muskegs are narrow; but the almost countless lakes, some of which are of large size, are serious impediments to land travel during the summer months. Winter travel is comparatively easy. The snow is not deep, and the large lakes afford the means of good travelling from the middle of December until the last of March. Summer roads are expensive and difficult to build on account of the large muskeg areas, and the large lakes make wide detours necessary unless boats are used and goods transhipped. The Saskatchewan is ordinarily a fairly good transportation route from June to October. During the past season, however, the water was extremely low, and during the months of September and October boats drawing only 2½ feet of water were unable to get over the bar at the outlet of Cumberland lake. Even when it is impossible to bring barges to the head of Sturgeon lake, ore must be hauled a considerable distance on sleighs. Ore mined at the Mandy during the winter is hauled 35 miles and stocked at Sturgeon lake until the opening of navigation. Ore hoisted last summer is now piled at the foot of Schist lake, 10 miles south of the mine. It is hoped that by means of locks on Schist creek barges can be brought directly from the mine to the south side of lake Athapapuskow, thus reducing the sleigh haul at that end to 17 miles. Ore brought down by the boats has had to be hauled some distance by teams at the Pas, as no spur has yet

been built from the railway to the waterfront. With a system of transportation such as this the additional handicap is imposed of a period of a month or six weeks in the spring and another in the autumn when all travel is impossible. Large lakes such as Sturgeon and Athapapuskow do not freeze until December, but the smaller lakes and creeks freeze early in November. Thus canoe travel is impossible on account of the closing of the small lakes, and travel by teams or on foot is equally impossible because of the lack of roads around the big lakes. Hence any company operating at the present time must be prepared to submit to being cut off from communication with the outside world during these two periods.

GEOLOGY OF THE SCHIST LAKE DISTRICT

The sulphide ore deposits are found in the oldest series of rocks recognized in the district, but genetically they belong to a much later period. The wall rock of the Mandy deposit is chlorite schist associated with massive greenstone. At Flinflon the ore is also in a schistose zone in massive ellipsoidal-weathering lavas. Lithologically, the rocks are not unlike the Keewatin of Ontario, but they may, or may not, be of the same age. Northward these rocks are overlain by gneisses. A short distance northeast of Flinflon there is a small boss of granite porphyry which may be responsible for some of the sulphide, but not for the important mineralization. A thick series of sediments, largely conglomerate, arkose, and graywacke, overlies the greenstone series and is probably also later than the granite porphyry. All of these formations have been intruded by great batholiths of granite gneiss and massive granites. Sulphide lenses are found closely associated with dikes and small masses of these intrusives, and it is believed that to them must be ascribed the chief mineralization. The granite is the latest Pre-Cambrian formation and the last rock to be involved in the ore deposition. The Ordovician dolomite and the glacial and post-glacial deposits simply form a mantle over the older formations and have nothing to do with the ores except that they may possibly conceal them.

THE MINERAL DEPOSITS

The sulphide body at the Mandy is lenticular with a total length of 225 feet and a maximum width of 40 feet on the surface. The ore now being shipped is mined, however, from a mass of high-grade chalcopyrite 100 feet in length by 12 feet in width on the surface, and widening to over 18 feet at the 100-foot level. The ore-lens is separated from the schist of the footwall by a 10-foot band of pyrite, and between the chalcopyrite and the hanging-wall there are 10 to 12 feet of zinc blende and another band of pyrite. The segregation of these minerals is not as complete as this description suggests, but the chalcopyrite from the lens in the middle is sufficiently free from zinc to present no difficulty in smelting. Apparently during the close folding of the older rocks of the district the schistose bands at the Mandy were crumpled into a large drag fold which was mineralized by pyrite. A second period of fracturing occurred, opening up spaces in the first sulphide replacement, and chalcopyrite and zinc blende were introduced, filling these openings and replacing the earlier minerals. The alteration of the country rock is of the type produced by hot aqueous solutions, and it is reasonable to believe that these were the final emanations from the cooling granites that are found in the vicinity of the ore deposits.

The Flinflon orebody lies 4 miles northwest of the Mandy. It is a mineralized shear zone in massive greenstone. In places this deposit has a width of 75 feet of solid sulphides, and diamond drilling has proven the continuation of the mineralized zone for over 2,500 feet. It carries a smaller proportion of chalcopyrite and zinc blende to pyrite than the Mandy lens, and at Flinflon no segregation of sufficiently high copper content to bear the cost of transportation under present conditions has yet been discovered.

A few other prospects have received some attention, but these are as yet not important. Some of them show zones of chalcopyrite stringers which may be the margins of important ore-lenses, or which may not be associated with deposits of any size. This can only be determined by exploration. They are at any rate indications of other possible bodies of ore.

Although most of the ore produced has come from the Schist

Open-cut at the Mandy Mine

lake district, there has been considerable activity at Herb lake at the eastern end of the belt of basic pre-Cambrian rocks. Promising quartz veins are being developed on the claims of

the Northern Manitoba Mining Development Company, at the Rex, Elizabeth, Dauphin, and other properties. Only one small shipment has yet been made. This consisted of 28½ tons of quartz from the shaft of the Northern Manitoba Mining and Development Company, which returned $2,323. A mill has been installed on the Rex, and shafts are being sunk on several other claims. Herb lake is only 11 miles from the Hudson's Bay Railway, and a waggon-road has now been constructed which will serve fairly well the needs of a gold quartz mining camp.

The geology of the Herb lake district is somewhat similar to that of the Schist lake district, but among the lavas there are many acid flows. Some of the sediments are metamorphosed into staurolitic, cyanitic, and garnet schists, and the relations of these to the greenstone series and to the sedimentary gneisses is extremely complicated. The older highly metamorphosed rocks are intruded by diorite, granodiorite, and granite.

The veins are the typical lenticular quartz veins so commonly found in the Pre-Cambrian. The wall rocks in places carry considerable auriferous arsenopyrite, but in the quartz gold occurs native or as the telluride. Nests or masses of tourmaline are found in most veins, and the gold may occur in these as well as in quartz. Evidently, the gold veins are high temperature deposits and are probably directly connected with some of the late intrusives.

In this brief review of mining in northern Manitoba only those districts have been mentioned in which prospecting has led to actual mineral production. There are, however, several other areas of rocks similar to those at Schist lake and Herb lake, and with a return to normal conditions and the impetus that will be given to prospecting by the inauguration of actual mining, it seems certain that other districts will receive attention. Geological conditions at other places are essentially similar to those in this belt, and it seems not unlikely that sulphide lenses similar to those at Schist lake, and gold-bearing quartz veins like those at Herb lake, will be found in some of the unprospected areas of Manitoba, north of the Saskatchewan river.

THE ORIGIN OF THE GOLD DEPOSITS IN THE CANADIAN PRE-CAMBRIAN

By R. C. Wallace

There is now a literature of fairly considerable dimensions relating to the occurrence of gold in the quartz veins of the pre-Cambrian shield. The work has been necessarily in the main descriptive, but several investigators have kept as a definite objective the elucidation of the conditions which led to the precipitation of gold in the quartz veins. As the writer is engaged in a comparative study, with that end in view, of certain deposits—very dissimilar in type—on the western flank of the shield, he may perhaps be permitted to indicate some of the more important points to which, in his judgment, attention must specifically be directed, if the problem is to be solved. It is realized that only by the co-operative work of investigators in many fields will safe conclusions be reached; and it is felt that a statement of certain specific points, some of which are by no means new, may serve to crystallize thought and provoke discussion. The suggestions that are offered are tentative, and are open to criticism, whether destructive or constructive.

1. *The relation of the Laurentian granite to the mineralization.*—It is generally agreed that the quartz veins which carry the gold bear a close relationship to the post-Temiscamian (Algoman) granite. Some gold-bearing veins have, however, been found in granites which are undoubtedly Laurentian. It is important to determine, in cases where the granite is unquestionably of Laurentian age, the extent of the mineralization in the quartz veins associated therewith. If this earlier mineralization is found in any considerable extent, the question arises whether the re-solution of gold by heated meteoric or vadose waters at the time of later plutonic upwellings may have contributed in major part to the supply of gold for the later veins.

2. *The relation of the gold to the quartz veins.*—It is characteristic of the gold occurrences in the western part of the field, as in practically all the gold-fields in Ontario yet described, that

the gold is found lining fissures which were infilled after the quartz of the veins had solidified. So consistently is this the case that when gold is found, in thin section, showing no visible connection with fissures, care must be taken to determine whether the fissure may not lie in the plane in which the section was cut. The writer has not yet found, in the fields under his investigation, an absolutely clear case of gold deposition apart from the fissures. It is realized, as has already been pointed out by more than one investigator, that gold may perhaps be found sub-microscopically in the original quartz infilling. Other means of investigation than by the microscopic may be necessary in order to arrive at the facts of the case. Again, the fissures in which the gold occurs are to a large extent—probably mainly—true contraction fissures unconnected with shearing processes. The gold has entered at considerably lower temperatures, and at a considerably later date, than the veinstuff. There occur in the veins, sometimes in fairly large proportions, feldspar, biotite, even sphene and zircon. If the gold is found only in fissures, is it safe to draw conclusions from the association of gold with minerals of the granite suite as to the genetic association of the gold and the granite ?

3. *The gold-bearing solutions.*—The most direct and indisputable evidence of the nature of the solutions which carried the gold will be obtained by examining the minerals which line the fissures. So far as the writer's experience goes, these solutions appear to have been poorer in silicates than was to be expected. Notwithstanding the presence of secondary albite in the veinstuff, alkaline sulphides rather than alkaline silicates were probably the effective solvents and carriers of the metal. The more volatile constituents of the solution would hardly be trapped in the fissures where the gold is deposited, and a clue to the total composition of the solution cannot well be obtained. But sulphides are invariably associated with the gold in the fissures; even pyrrhotite, which is usually considered to be a high-temperature mineral, is in one field always present in the fissures with the gold, notwithstanding the fact that the fissures bear all the marks of having been infilled at relatively low temperatures.

4. *The influence of basic eruptives.*—Maclaren's suggestion that the gold in the pre-Cambrian of Canada, as of other countries, is genetically connected with basic rather than with acid rocks has not been accepted by workers in the Canadian field. The connection that can be traced between late granites, quartz veins and gold in all the fields that have been studied is so close that the facts seem to point in another direction. Certain basic dykes in the western field are found to exercise a selective attraction for gold where they occur in close proximity to the quartz veins. It is of interest to determine to what extent this is true throughout the pre-Cambrian, and what is the underlying reason. A gradual shift of the isothermal lines surfacewards—from whatever reason—might lead to refusion of the crustal material on a large scale into granite, and to a concentration in special channels of the gold therein contained; or the underlying more fluid basic magma might escape to the surface, carrying with it, though only under specially favourable conditions, that part of the gold which was enabled, by virtue of its volatile carriers, to reach the orifice through which the magma dissolved its way to the surface.

5. *The determination of the age of the granites.*—The ever-present difficulty is the determination of the age of the granite from which, in any district, the quartz veins appear to rise. To put it figuratively, the initiative is now with the Algoman, and the Laurentian is fighting to keep the territory which was once her own without a question. In many districts the only criterion that the field observer has is the character of the granite. Only in the relatively few localities may evidence be obtained, either from the unconformable attitude of the conglomerate to the granite on the one hand, or from the intrusive relationship of the granite with the conglomerate on the other. In many areas the investigator is at the present stage perforce thrown back on the mineralogical composition and on the structure of the granite for some clue as to the relative age of the rock. Lawson has pointed the way to a petrological study of the granites by discriminating on mineralogical grounds between the older and the younger granites in the Rainy Lake area. If the much-to-be-desired petrological test as to the relative ages

of the granites be ever possible of application, its formulation can only be reached after careful study of the distinctive characters of the Laurentian and Algoman granites over a very wide field. It may be that positive results are not to be attained: but negative results would be of value at a time when petrological and structural tests are undoubtedly being used for correlation purposes.

Discussion

Mr. F. J. Alcock (*communication to the Secretary*): Dr. R. C. Wallace has summarized some of the problems in connection with the origin of the gold deposits in the Canadian field; no particular field was referred to, but a number of suggestions were offered which were thought might apply in general to this widespread type of deposit. The work of the writer in the Wekusko Lake district, one of the three fields of the province of Manitoba in which gold-bearing quartz veins have been located and the first of these to develop a producing mine, has led him to conclusions which differ in some respects from those offered, and a brief continuation of the discussion is, therefore, probably desirable.

The origin of the quartz veins.—The following facts about the quartz veins of Wekusko lake are considered significant:

The veins are found traversing all the pre-Cambrian rocks of the region, including the granite.

The youngest intrusive is granite with accompanying pegmatite and lamprophyre dykes.

Many of the veins of the district contain feldspar and approach pegmatite in composition.

The granite locally contains arsenopyrite, a mineral found in nearly all the veins.

Tourmaline, a characteristic pneumatolytic mineral, is very abundant in some of the veins.

The six main properties of the area are situated along the border of a granitic stock which has a diameter of approximately four miles; one of these veins is along the actual contact of the intrusive and the intruded schist, three lie at a distance of less than two miles, and the remaining two at a distance of three miles from the surface outcrop of the stock. The character of the granite contacts throughout the area also suggests the widening of the stocks with depth, which would reduce the distance of the veins from the granite mass. The stock referred to has produced extensive contact metamorphic effects, with the development of garnet and staurolite bearing schists and gneisses.

The veins are not extensively sheared as would be expected if they were older than the latest period of granitic intrusion with its accompanying deformation.

It is to be concluded, therefore, that most of the veins, at least of the Wekusko Lake region, are to be attributed to the latest period of granitic intrusion. It is, of course, probable that older granites produce veins, but absolute proof of the existence in place of these older granites in the Wekusko Lake field is difficult to obtain. Fresh granite boulders are found in conglomerates which are older than the regional granite, but until the actual existence in place of these older granites is definitely proved, little can be said for them as a source for the gold.

The question of using the terms Laurentian and Algoman with reference to granites in the western fields is one against which much can be urged. Though, as has been stated, it is difficult to prove the existence in place of older granites in the field, there is structural evidence in the Wekusko Lake area for three periods of granitic intrusion. Moreover, since even in the fields where these terms were originally employed, geologists are not agreed as to their use, an avoidance of these terms seems desirable.

The origin of the gold.—Dr. Wallace refers to the presence of gold in fissures in the quartz veins, and concludes that it has been introduced at relatively low temperatures and at a considerably later date than the vein material; doubt is also cast upon the

genetic relationships of the gold and the granite. Some of the features observed by the writer in the Wekusko Lake region, which bear upon this point, may briefly be summarized as follows: the vein quartz is commonly granular, white to brownish in colour, and only rarely shows a banded structure; the gold is concentrated chiefly along dark streaks in the quartz; these streaks are usually short and very irregular and patchy; sulphides and tourmaline nearly always accompany the gold; gold is, however, found as isolated specks in the quartz away from any of the dark streaks; specimens were collected in which gold in visible quantities was found completely enclosed in masses of tourmaline. The intimate association of the gold with the tourmaline in a number of veins shows that the same origin must be assigned to both minerals. The deposits, therefore, have the characteristics of those formed at high temperatures rather than at low or even intermediate temperatures.

Conclusion.—The theory held by the writer for the quartz veins he has observed is that which has generally been advanced for the gold-bearing veins of the Canadian shield. The intrusion of granite batholiths was accompanied by deformation which produced fractures, shear planes, anticlinal openings, and other lines of weakness. As the main granite mass cooled the volatile constituents became concentrated in the remaining part of the magma. These gave rise in the later stages of intrusion to pegmatite dykes and quartz veins. The formation of the veins was a process which proceeded slowly, and in places the primary quartz was crushed and minerals, including gold, deposited in the fractured areas; but the whole was essentially one process related to the granite intrusion. The deposition took place at high temperatures, and it was only by denudation in pre-Ordovician times that the veins as seen to-day were brought to the surface.

THE FORMATION OF OREBODIES

By J. D. Kendall

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INTRODUCTORY

Ore, from the standpoint of the miner and metallurgist, is mineral matter containing one or more of the useful metals in such quantity and combination that their extraction can be effected at a profit. In the United States and Canada such ore is spoken of as 'pay-ore,' to distinguish it from similar mineral matter which cannot, in the circumstances prevailing, be profitably worked.

Some ores contain only one principal metallic mineral, like the ores of iron. Others, like argentiferous galena, contain two or, as in the case of argentiferous and auriferous copper ores, they may contain three.

It must have been observed by all mining men of wide experience in metalliferous deposits that there is an almost invariable association of certain metallic minerals in ore deposits which cannot possibly be accidental. For example, we find, almost without exception, that lead-bearing deposits contain also blende and pyrite, or their alteration products. In copper-bearing deposits the associated minerals are commonly either chalcopyrite, pyrite, and pyrrhotite, or alterations of those minerals. In other cases we find gold, silver, and pyrite occurring together, or cassiterite, wolframite, and arsenopyrite. Gold-bearing deposits are usually accompanied by quartz. These associations and others are so common that they call for an explanation. In the many writings on genesis that have from time to time appeared the facts are mentioned, but there is no attempt at explanation so far as I know.

Another feature of most ore deposits is their connection with either eruptive rocks, fault planes, or well-defined joints in the containing rocks. Their intimate association with eruptives has led some writers to look upon these rocks as the immediate source of the metallic minerals occurring in ores, but this view is much obscured by the fact, above-mentioned, that certain metallic minerals are found together in orebodies which have not been so found in igneous rocks. Further, these minerals are found together in deposits occurring both in aqueous and igneous

rocks, and whether there are or are not igneous rocks of any importance in the neighbourhood of the former. For example, in the lead-bearing deposits in the carboniferous limestone of Leadville, Colorado, as well as in the limestones and sandstones of the Yoredales of Alston Moor, Allendale, and Weardale, we find galena, blende, and pyrite, or their altered representatives. In the former district the bed of limestone containing the principal orebodies is overlain and much intersected by extensive masses of igneous rock, which Mr. Emmons, who made a very thorough examination of these deposits in the early days of their development, looked upon as a possible source of some, if not the whole, of the ores occurring at Leadville. In the Alston and Weardale district the rocks are all of aqueous origin except the comparatively insignificant intrusive sheet known as the 'Whin Sill,' which occurs near the base of the Yordales and altogether below the ore-bearing strata. Mr. Wm. Wallace[1] says that "in Alston Moor the veins have been most productive in situations farthest removed from plutonic action." In saying this, Mr. Wallace could have had in mind only that phase of plutonic action which results in the production of igneous rocks, for the district is very much intersected by fault-planes which, in most cases, if not all, are due to hypogene action.

A peculiarity of some minerals is that they seem to prefer particular kinds of rocks, as for example, the apparent preference of cassiterite for granite. Why is this ?

Ore deposits occur in rocks of almost all ages, from the Archæan upwards, but the age of the deposits is not necessarily the same as that of the rocks containing them, and may be very different. Most ore deposits of determined age seem to have come into existence during, or immediately after, periods of more or less violent subterranean disturbance. This conclusion, in particular, leads us back in search of explanations to that far distant period of terrestrial evolution when some of the rock constituents had cooled down to such an extent that a solid crust was forming. Let us imagine what then took place. Except the permanent gases, the various chemical elements (or

[1]Deposition of lead ores in veins, 1861.

combinations of them) had liquefied and taken up a position in the heated magma dependent partly upon specific gravity, partly upon the melting or boiling point. When the outer crust had cooled below 212° F. a hydrosphere would be formed, and above that an atmosphere. The initial crust would, in all probability, be somewhat akin to the acid eruptives with which we are now familiar. It would almost certainly become more basic with increasing depth, at a rate depending upon the proportionate quantity of the various minerals formed.

The thoughts arising in connection with the above seem to have such an intimate bearing on the genesis of ore deposits that they will be introduced with their relative facts, and developed as an initial step in the enquiry.

PART I

General Facts, Suggestions and Explanations

Crust Forming.—What combinations were primarily formed by the cooling elements in the cosmic process we may to a certain extent, perhaps, infer from what we know of the composition of eruptives. The mineral constituents of these have been divided by Rosenbusch[2] into four groups:

(1) The ores and their accessory constituents—Magnetite, Hematite, Ilmenite, Apatite, Zircon, Spinel, Sphene, etc.

(2) The ferro-magnesian constituents—Biotite, Hornblende, Pyroxene and Olivine.

(3) The felspathic constituents—Felspar, Nepheline, Leucite, Melilite, Sodalite, Hauyne.

(4) Free Silica.

The minerals of each group and also those of different groups have formed, in a general way, in the cooling magma of many

[2]Über das Wesen der Körnigen und porphyrischen Structur bei Massengesteinen. Newes Jahrbuch, 1882.

rocks in the order of decreasing basicity. But there are numerous exceptions to the order. Magnetite, for example, is not always the first product of consolidation. It may be found at almost any stage.[3] Quartz precedes the felspars in many granites[4] and oligoclase sometimes precedes orthoclase.[5]

Of the various metallic minerals known to us that are heavier than aluminium only oxides of iron form an appreciable part in the composition of rocks. Others are found in infinitesimal quantities in some rocks, both igneous and aqueous, but it is not clear whether they formed part of the elevated and erupted magmas or are later impregnations.

The following table gives the specific gravities, the fusing, boiling and volatilizing temperatures of some of the commoner heavy metals and minerals:

	Specific Gravity	Melting Point °C.	Boiling Point °C.	Volatilizes at °C.
Antimony	6.71	440	1090–1450	Bright red head.
SbO_3	5.2			
Arsenic	5.8	412		449 to 450
AsO_3	3.7			
Bismuth	9.8	264	Between 1090 & 1450	At high temperature.
BiO_3	4.4			
Cobalt	8.5	1500		
Copper	8.9	1045		
CuO	5.8			At highest temperature of wind furnace.
Gold	19.3	1050		1100*
Iron (white cast)	7.8	1050		
Iron (grey)		1200		
Fe_3O_4	5.0	1250		

*Increases rapidly with temperature.

[3]Fouqué and Levy. Synthése des Mineraux et des Roches, p. 51.
[4]J. Roth. Allgemeine und Chemische Geologie. Band II, p. 50.
[5]De la Valée, Poussin et Renard. Mém. sur les Roches plutoniennes. &c.

	Specific Gravity	Melting Point °C.	Boiling Point °C.	Volatilizes at °C.
Lead	11.25	335	1040	Begins at a bright red heat.
PbO	9.36			White heat.
Manganese		1247		
Nickel	8.3	1410		
Platinum	21.5	1790		
Silver	10.5	1020		At high temperature.
AgCl	5.5			At red heat.
Tellurium	5.8	455		do
Tin	7.3	235	Between 1600 & 1800	
SnO_2	6.9			
Tungsten	19.1	1700		
$(FeMn)WO_3$	7.3			
Zinc	6.9	415	1040	Bright red heat.
ZnO	5.6			Strong white heat.

What chemical combinations were formed by the metals as they cooled from the nebulous vapours we can only surmise, but probably they were mostly oxides. The sulphides of the heavy metals when heated in contact with air are changed to metals or oxides. The specific gravities of the compounds, although lower than those of the metals, would probably in many cases preserve approximately the relativity of the latter.

The most abundant elements occurring in the earth's accessible crust have been estimated approximately as follows:

	per cent
Oxygen	47
Silicon	28
Aluminium	8.16
Iron	4.64

	per cent
Calcium	3.5
Magnesium	2.62
Potassium	2.35
Sodium	2.63
	98.90

The remaining 1.1 per cent consist of:

Hydrogen	.17
Carbon	.12
Phosphorus	.09
Sulphur	.07
Chlorine	.04
Fluorine	.01
Nitrogen	.02
Titanium	.41
Manganese	.07
Barium	.05
Strontium	.02
Chromium	.01
Nickel	.01
Lithium	.01
	1.10

Metallic minerals, such as gold, silver, copper, tin, lead, and zinc, as they are scattered through the rocks, are so small in quantity that their percentage would be expressed in the fourth to the eighth place of decimals.

Over 83 per cent of the oxygen is taken up in forming silica and alumina, and about 14 per cent in forming iron oxide, lime, magnesia, soda and potash, the remaining 3 per cent being divided among the other elements. Some of the combinations of these elements as determined by chemical analysis, are given below, which is the average result of 830 analyses[6] of rocks of the different kinds known to us.

[6]By F. W. Clarke, Bulletin 78 of the U.S. Geol. Sur., pp. 34-43.

	per cent
SiO_2	59.71
Al_2O_3	15.41
Fe_2O_3	2.63
FeO	3.52
CaO	4.90
MgO	4.36
K_2O	2.80
Na_2O	3.55
H_2O	1.52
TiO_2	.60
P_2O_5	.22
	99.22

It seems fairly certain that the minerals of the primeval magma would be concentrated, whilst in a fluid condition, more or less in accordance with the specific gravities of the combined elements; the heavier the mineral, the deeper it would sink, other conditions being equal, just as we see in the settlers of a copper smelter the copper-bearing matte sink to the bottom whilst the lighter siliceous slag flows off from the top. The inference is further supported by the fact that the density of the earth, as a whole, is nearly twice that of the average of the minerals accessible from its surface. In the eruptives on and near the earth's surface we find minerals of very different specific gravities in the same rock—for example, quartz and magnetite—but that may be the result of either later hypogene action by which minerals from different horizons beneath the surface—that is, of different specific gravities—were brought together; or it may be that the relatively small quantity of iron ore found in igneous rocks generally became so entangled in the cooling magma that complete concentration and separation into distinct horizons of approximately equal specific gravities could not be effected, just as we find pellets of matte in the slags of copper smelters even when very large settlers are employed. The minerals forming the major part of what we know as basic eruptives would, in all probability, form lower zones than the lighter minerals

which constitute the bulk of the acid eruptives, but it is easily conceivable how, during subterranean disturbances, they might become more or less mixed. Indeed, such a mixture of minerals of different specific gravities may extend downwards indefinitely through zones of increasingly heavier materials. The basic eruptives contain more iron ore than the lighter acid rocks, doubtless because the separation would be more difficult in the former case owing to the higher specific gravity of the associated minerals in the basic magmas as compared with those of the acid magmas. This suggestion is, to a certain extent, similar to that favoured by Durocher, who regarded all rocks as referable to two superimposed layers—an acid layer on the top having a specific gravity of 2.65 and a basic layer below with a mean specific gravity of 2.96.

The order in which igneous matter has been ejected from ancient volcanoes is not strictly that of acidity to basicity, nor is that to be expected, as the character of the ejections would, to a large extent, depend upon the depth at which the volcanic action originated.

Whether the surface of the globe, when it had cooled down to a solid condition, was a regular oblate spheroid, or whether the newly formed rocks were everywhere of the same mineralogical character on the surface, we cannot say, but we know that since then, by internal disturbances, upheavals and depressions, by denudation, igneous eruptions and aqueous deposition, the form of the earth's surface and the character of its rocks have undergone great and varied changes.

The igneous intrusions and extrusions, as well as a large portion of the fault-planes by which rocks are much intersected, extend from unascertained depths below the surface, and they both, as well as the ruptured rocks adjoining them, probably formed channels by which the heavier metallic minerals, found in ore deposits, made their way from the deeper parts of the primeval magma—the barysphere—to the higher levels on which we now find them.

How deep the solid crust may be we have no means of

knowing. Some writers consider that the melting point of rocks is so raised, by increasing pressure downwards, that the lithosphere may extend to depths far below those at which the melting point of rock-forming minerals would otherwise be reached. Let us see if such a view is maintainable. The weights by which different rocks are crushed, in small cubes, varies greatly, as shown by the following table:—

Rock	Crushing Weight Tons per square inch
Granite, Aberdeen	4.87
Greenstone, Irish	9.3
Quartz Rock, Holyhead	11.4
Statuary Marble	1.44
Limestone, magnesian	1.36
Limestone, Purbeck	4.09
Slates, Irish, on bed	10.6
" " on edge	6.23
Sandstone, Yorkshire Paving	2.55
" Red	.97
" Arbroath Pavement	3.52

Taking the average weight of rock to be about 165 lb. per cubic foot, or 1.14 lb. in a column one inch square and twelve inches high, a rock having a crushing strength of four tons per square inch would be crushed at a depth of about 10,000 feet, if each layer of rock had to bear the weight of all the rock above it; that is to say, under such a pressure all sandstones and limestones would be so crushed that their fossil organic contents would be quite deformed; but we know that such is not the case, and when we come to consider the matter, it seems quite clear that rocks have not had to bear any such stresses. In larger blocks than those tested the resistance to crushing might be higher per square inch than stated in the above table, but not sufficiently so to affect the argument. A section of the earth's crust may be looked upon as a ring, the strains in which, for lengths up to 2,000 miles or so, may be considered as being

borne similarly to those of a segmental brick arch, in which each ring of bricks bears its own weight after the closing brick has been inserted. The stresses are lateral, passing both ways from the centre into the abutments. Looked at from this point of view, the deeper layers of rock in the earth do not bear much, if any, more weight—after consolidation of the sedimentaries—than the upper layers. The deformation of some fossils, which we know has taken place, is more probably due to lateral rather than to vertical pressure. The same lateral pressure, occasionally increased by local sinkings and igneous intrusions, has also produced the cleavage of slaty rocks, the sheeting of many igneous rocks, and the jointing that is such a marked feature of limestones, sandstones, and argillaceous rocks. The different sets of jointing in rocks—often nearly at right angles to one another and to the bedplanes—are a consequence of the spheroidal form of the earth. Had that been cylindrical, probably only one set of jointing would have been produced. The directions of stress have doubtless been, from time to time, altered by extensive igneous intrusions.

The stability of a segmental brick arch, when loaded at the centre, is secured by previously loading the haunches. If, therefore, to carry out the comparison of a part of the earth's crust to a brick arch, it is assured that certain portions of the first formed crust, such as those under the Atlantic and Pacific Oceans, sank on to the cooling and contracting matter below, as shown by the dotted line 1 between *a* and *b* (Fig. 1), other portions of the crust, on opposite margins of the sinking areas—corresponding to the haunches of an arch—would rise as shown by the dotted lines (1) between *c*, *d* and *e*, *f* (Fig. 1), in consequence of their not being sufficiently loaded. Probably the sinking areas would not be so regular in section as shown in Fig. 1, but, consequent upon lateral pressure, would be more or less undulating. When portions between *a*, *b* and *c*, *d* had risen above the surface of the hydrosphere they would be attacked by meteoric forces and the material denuded from them would be deposited on the sinking areas adjoining; which, in consequence of the added weight, would sink still farther, at intervals, as shown by the dotted line 2.

Fig 1

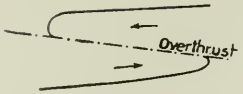

Fig 2

Fig 3

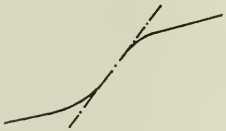

Fig 4

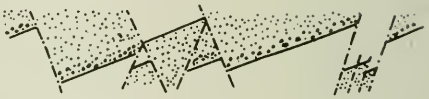

Fig 5

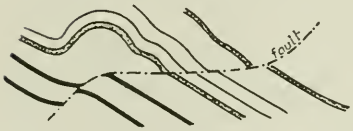

Fig 6.

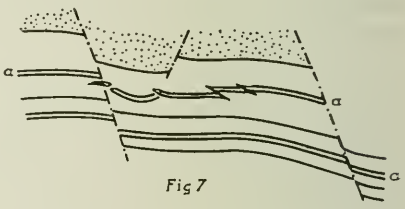

Fig 7

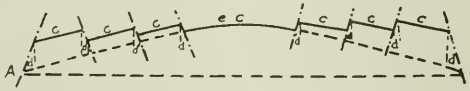

Fig 8

The initial crust-sinking, between *a* and *b*, and in other areas was probably due to some inherent local weaknesses, causing them to follow closely on the contracting molten nucleus.

The rising of the crust at *c*, *d* and *e*, *f*, was doubtless the initiation of our continental areas. It is, moreover, closely associated with mountain building. The rupture of the crust in these areas would provide exits for molten matter from below,

which would further add to the mass of the nascent mountains. Continued denudation of these ranges and deposition between *a* and *b* of the material coming from them would cause still further subsidence between the latter points.

As the first formed crust rose to form the initial continental areas, the underlying molten matter would follow it up and sooner or later break through, being urged upwards by the expansion of the occluded gases. Owing to the severely shattered state of the crust there, the highly heated ascending magma would come into contact with water-saturated rocks and melt them, converting the included water into high pressure steam, which, with other included gases, would force the column or columns of molten matter far above the normal level of the upper surface of the hydrosphere and give rise to volcanoes.

When *c*, *d* and *e*, *f* first appeared above the hydrosphere they would probably be narrow. Further elevation would add to their breadth and bring under the influence of meteoric forces part of the sedimentary beds formed since the first appearance of dry land. Continued denudation, repeated depressions, elevations, faultings and extrusions of molten matter would ultimately produce the structurally complicated continental areas as we see them to-day.

That portion of the earth's crust which, in the different continents and islands stands above the sea level—which must have come from elevations of the crust or ejections from the barysphere—is equal in volume to a lenticular belt extending from pole to pole, 270 miles wide at the equator and 15 miles deep throughout. To that has to be added those parts of the crust displacing the hydrosphere under the continental areas. The ejection and elevation of all that material, the turning up, crumpling and folding of the rocks on the continental areas made way for additional subsidence of the ocean floor beyond that due to the contraction of the barysphere from loss of heat.

The ocean basins occupy about 72% of the earth's surface, and their average depth is about 11,800 feet or nearly 5,000 feet deeper than the original hydrosphere. The greatest depth is nearly 25,000 feet.

Subsiding and rising areas having been established on different parts of the earth's surface, they would persist to a greater or less extent. Depressions of part of the land areas and uplifting of the sunken portions we know have often occurred, but on the whole the former would sink, the latter rise, more or less interruptedly, owing to the crust being thinner and lighter and more fractured there, but the elevated masses would be continually reduced by denudation.

To revert to the question of the depth to which the solid crust may extend: We know that there is a uniform temperature of about 52° F. at a depth of 100 feet, in temperate regions. We also know that the temperature increases downwards at rates which vary in different areas, and that, in places, if not everywhere, the rate increases with depth. The following tables give the temperatures at different depths as observed at three widely distant points on the earth:

Rosebridge Colliery,[7] Lancashire, England

Depth Feet	Temperature of Rock (F.) Degrees
1674	78
1815	80
1890	83
1989	85
2013	86
2037	87
2202	88½
2235	89
2283	90½
2325	91½
2349	92
2400	93

Rosebridge Colliery,[7] Lancashire, England

Depth Feet	Temperature of Rock (F.) Degrees
2418	93½
2445	94

Tresevean Mine,[8] Cornwall

Depth Feet	Temperature of Rock Degrees (F.)
156	52.8
1200	75.5
1500	82.0

[7]Reports of Committee on Underground Temperature. Brit. Assoc. Reports, 1868-79.

[8]Brit. Assoc. Report, 1837, p. 133-137.

Forman Shaft,[9] Comstock Mine, Nevada

Depth Feet	Observed Temperature (F.) Of Rock	Observed Temperature (F.) Of Water
	Degrees	Degrees
100	50.5	
200	55	
300	62	
400	60	62
500	68	65
600	71.5	70
700	74.8	73
800	76.5	75
900	78	77.5
1000	81.5	80.5
1100	84	83
1200	89.3	91

Forman Shaft,[9] Comstock Mine, Nevada

Depth Feet	Observed Temperature (F.) Of Rock	Observed Temperature (F.) Of Water
	Degrees	Degrees
1300	91.5	94
1400	96.5	100
1500	101	104
1600	103	106
1700	104.5	
1800	105.5	
1900	106	
2000	111	
2100	119	
2200	116	
2300	121	

At Rosebridge the rise of temperature between 100 and 1674 feet is 1 degree for every 60 feet, or thereabout, and from 1674 to 2445 feet it is 1 degree every 48 feet. At Tresevean the rise is 1 degree in 48 feet. At the Forman shaft, between 100 and 1100 feet, the rise of temperature, as measured in the rock, is 1 degree every 29.8 feet, and from 110 to 2100 feet it is 1 degree every 28.6 feet. The temperatures observed here, it will be seen, are much higher than those recorded for either Rosebridge or Tresevean. This may be due to the greater chemical action in the rocks at Comstock, but it is more likely to arise from the comparatively open nature of the igneous rocks which occur there, permitting the passage of rock-heated water from below more freely than the rocks at either Rosebridge or Tresevean. The rocks at both Comstock mine and Steamboat Springs are only of Tertiary age, so that it is quite conceivable—knowing how very slowly such rocks cool—that there are highly heated

[9]Geol. of Comstock Lode, by G. F. Becker, 1882.

rocks at no great depth below. Steamboat Springs, from which water issues at a temperature of 167° F., and sometimes more, are only 7 miles from the Comstock Mines.

At the St. John del Rey Mines, in Minas Geraes, Brazil, the rock temperature at a depth of 4032 feet is 98° F., the rise in that case being 1° for about 85 feet.

Professor Prestwich[10] gives the mean increment for coal mines as 1° F. per 49½ feet, for other mines 43.2 feet, and for Artesian wells 50 feet.

At the upper part of the barysphere there must be a transition zone—graduating into the molten magma below and into rock above. Being of various degrees of plasticity it will be devoid of jointing of any kind. The thickness of this zone is also unknown, but it seems certain that it will occur at a gradually increasing depth as a result of cooling—the upper portion becoming part of the lithosphere, whilst the lower part is added to by solidifying magma. How deep the fiery liquid below may be is quite uncertain, but it seems clear that as the pressure increases downward the hot liquid matter will gradually become solid, and in all probability so continue until the layer has become strong enough to be self-supporting like the external crust. The downward pressure on the underlying material would then be reduced—the solid would probably again become liquid for some depth, owing to the reduced pressure, but like the first liquid layer would gradually become solid downwards. The alternation of liquid and solid would probably continue to the earth's centre. In the deeper layers, metals heavier than iridium may be locked up and never reach the lithosphere.

At the depth of about 15 miles or less, if the above rate of increase was maintained, the temperature of molten iron would probably be reached.

The strains and stresses caused by the repeated elevations and depressions of the crust and the breaking through of igneous matter doubtless initiated the innumerable faults by which it is intersected and which have played such an important part in the formation of orebodies.

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[10]Proc. Royal Soc., London, Vol. XLI, 1886, pp. 1-116.

Fault Forming.—Two kinds of fault-planes are generally recognized, one produced when the earth's crust is in a state of tension, the other arising from excessive lateral compression. The latter are known as reversed faults, or, when on an extensive scale, as overthrusts or thrust-planes. When any part of the earth's surface subsided over a large area, as we know it often has done, the rocks within that area would be subjected to an additional lateral compressive stress which, unless relieved, would increase with the amount of subsidence until the surface of the sunken area corresponded with the chord of any arc of the affected zone. Additional lateral compression would also be induced by the bursting up through the rocks of masses of molten matter, such as we know have taken place repeatedly in all ages. To one or other, or both, of these sources of lateral stress, added to that due to the weight of the crust, we may, I think, attribute all the crumpling, the folding, the rolling movements and the reversed fault-planes that have so seriously modified the original structure of the rocks. Overthrusts are perhaps always, and reversed faults sometimes, associated with folds or rolls of the strata, as in Figs. 2 and 3.

Rolls are sometimes seen along with faults of extension, which dip in the same direction as the strata, as shown in Fig. 4.

Faults, which dip in the same direction as the strata they intersect, frequently occur where there is not any evidence of a roll, as in Fig. 5.

The localization of any of the three kinds of faults shown in Figs. 2, 3 and 4 is probably due to the fracture of the rocks at the quick bends of the rolls or folds, so that, in the cases of the first two, further lateral compressive stress, as indicated by the arrows, resulted in a sliding movement along a plane passing through the reverse bends of the folds or rolls. The fault in the third case, shown in Fig. 4, was most probably produced by tensile strain and upward pressure, after the roll had been formed by compression.

A curious mixture of compression in association with faults of extension is sometimes seen, as shown in Figs. 6 and 7.

Tensile strain and differential upward movement, in all probability, also gave rise to the commoner kinds of faults. These are all faults of extension, and their hade or dip is very often practically at right angles to the inclination of the strata, or, in other words, their dip is in the opposite direction to that of the beds they intersect, as shown in Fig. 8.

The left half of this sketch shows the way in which the faults in the Whitehaven hematite district actually occur, the rocks on the left of *A* being coal measures and Permians. On the right of *A*, as far as *e*, they are Yoredales and Carboniferous limestones mainly, and between *e* and the crown of the dome, Ordovicians.

Faults of this description are, perhaps, always caused by a more or less extensive uplift. The rocks then under tensile strain, are fractured, to a greater or less extent, along the most persistent joints, and pushed upward into a number of steps, as shown in Fig. 8, by the heated fluid mass producing the upward movement. Let it be assumed that the tilted and faulted bed lay originally at *A*, *B*. A sufficient upward force, acting on it so as to cause it to rise into a circular or elliptical dome, must produce a tensile strain on the uplifted rocks that would break the bed at the weakest points into parts as shown, which parts, after tilting a little dipward, would, by the uniform upward pressure of the fluid mass below, be forced into the steps indicated, and they would stop rising only when the extended length, due to the uplift, was accounted for by the sum of the spaces *d*, *d*, *d*, in Fig. 8. If the uplift, and the strains induced by it, were great and the faults few, the latter would probably be of large throw as the spaces *d*, *d*, *d*, would be comparatively large. But, if the uplift were small the extension would be so little that the throw of the faults would of necessity be small. In writing of faults of this description, in the Leadville District, S. F. Emmons[11], says: "The plane of the fault slopes away from the side which has

[11]Geol. Sur. U.S.A. Geology and Mining Industry of Leadville, Colorado, p. 287.

Fig 9

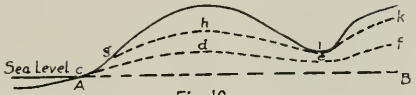


Fig 10

Fig 11. A. Sandstone
B. Shale
C. Limestone

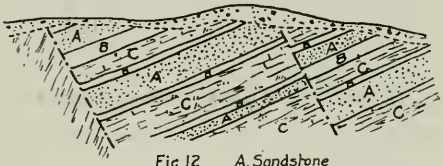


Fig 12 A. Sandstone
B. Shale
C. Limestone

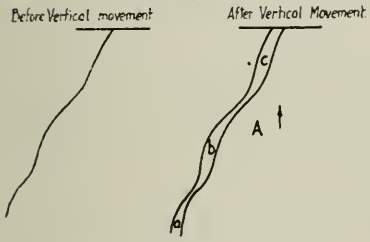


Fig 13 Fig 14

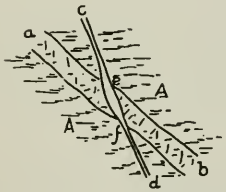


Fig 15 a.b. Elvan dyke
c.d Tin-bearing Vein
A. Slate.

Fig 16 A Argillite
B " decomposed &
Cerussite & Limonite
C Galena

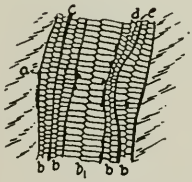


Fig 17. a. Chalcopyrite
b Quartz
b_1 " with blend & Chalcopyrite.
C. Clay.
d Vug.

risen; this is the condition which generally prevails, and it is explained on the theory that the uplifted side has thus a broader base than the downthrow side." This idea was also held by

W. Hopkins[12] and is very prevalent, but clearly it cannot be maintained. The faults shown in Fig. 8 are parallel, both in direction and hade, and some of the blocks of ground on the up-side are *narrower* than those on the down-side.

In the centre of Fig. 8 we see what is sometimes called a trough-fault, supposed by some writers to have been produced by a sinking of the wedge piece, but it is due really to the rise of the blocks between which it lies.

Some faults die out in both directions and have not much throw at any point. Such faults may be caused by gas under great pressure, by small igneous intrusions that have not reached the surface, or by compression of the rocks on one side of a persistent joint which induced the bending of the rocks on that side, thus:

Where the strata are tilted at suitable angles faults of extension are occasionally coincident with the bedding. Reverse faults are likewise so found. In some cases faults are co-incident with dykes.

Some small faults have come into existence during the deposition of the strata in which they occur, as shown in Fig. 9.

The earth's crust, in the continental areas, is split up by innumerable faults into blocks of many shapes and sizes. The smaller faults may not extend to great depths—perhaps terminating in some expansible bed—but the larger faults in all probability go down to the plastic zone between the lithosphere and the barysphere. Whether deep or shallow, we know that they, at all times, exercise an important influence on the circulation of underground waters. At times of more or less violent movement some of them would, in all probability, carry solutions of mineral matter which might give rise to ore deposits alongside them, or in rocks extending to some distance from them, provided there were suitable channels in those rocks for the circulation of the mineral waters.

The directions of faults vary greatly, even in the same

[12]Theories of Elevation and Earthquakes. Brit. Assoc. Report. 1847, p. 63.

district. Taken in the aggregate they may be said to have almost every direction, but they may be divided into two groups, one of which lies between 38 N.W. and S.E., and 35 N.E. and S.W., the other between 56 N.W. and S.E., and 63 S.W. and N.E. The strong joints do the same. So do the principal mountain ranges. Joints are lines of weakness, and it is to be expected that fault-movements very frequently would take place, to a large extent, along those lines. For the same reason the upheavals depicted in Fig. 1 would be determined by the two sets of jointing, in the same way as a brick arch, insufficiently loaded at the haunches, would, if the crown came down, rise at the haunches along the longitudinal joints of the brickwork, about midway between the crown and the abutments.

The differential movements along fault-planes have been both vertical and horizontal, and sometimes a combination of the two, as shewn by striæ and groovings on the movement-planes. The throw of some of the smaller faults may have been reached at one movement. In the larger faults it may cover an extended period, the movements being comparatively small and more or less intermittent.

Very many mineral deposits are on the lines of faults—some of which have had important differential movements since the deposits were formed, as shewn by the slickensides on the ore—and it is well known to miners that veins having certain directions are more frequently productive than others in the same district, which differ from these directions only by a few degrees. The reason of this is probably that the less productive, or non-productive, veins are on the lines of faults which came into existence after the liquids which formed the productive veins had nearly or quite ceased to flow. In many cases an increased quantity of ore is found at the intersection of faults (or strong joints). This is to be expected if both sets of faults (or joints) preceded the advent of the ore-bearing solution, but not otherwise. There is no doubt that faults have been formed at many different times, which doubtless accounts for their many directions. It has been shown, for example, by Revol[13] that, in the neighbourhood of

[13]Sur les Filons de Galène Argentifère de Vialas. Annales des Mines, Vol. IV, 1863, p. 329.

Vialas, in the department of Lozère, France, there are eight groups of veins of different ages and having different directions; three groups lying between 40 N.W. and S.E., and 26 N.E. and S.W., and five groups between 70 N.W. and S.E., and 49 S.W. and N.E. The most important group bears 57 S.W. and N.E.

As most faults are the result of uplifts, it would seem a fair inference that the direction of the faults would, to a large extent, be determined by the direction of the uplifts and be more or less parallel to the axes thereof; for the tensile strain put on the rocks, as they were uplifted, would be at right angles to the axes of the uplifts, and therefore the faults would be more or less parallel to those axes.

Veins having a low dip, like some of the Californian gold veins, are most probably on the lines of overthrusts.

Distribution and Circulation of Underground Water.—All underground water must, at all times, have fallen as rain on to the earth's surface, and then sunk into the rocks. At the present time we know that part of the rainfall flows off the land by streams and rivers to the sea, to be evaporated and form more rain. Some is evaporated from the land surface, but much of it sinks into the earth and is carried by joints and faults and through the interstices of the rocks to various depths and in many directions determined by geological structure and orological features. The circulation due to gravity must be mainly above sea level, A, B, Fig. 10. It is not likely that it will, in any quantity, extend far below that level, except in uncommon circumstances, as the friction of the rocks would so reduce the hydraulic head that movement would soon become nil.

There would also be more or less stagnant water above sea level, according to the mineral character and structure of the ground. If that were of a porous and jointy character the surface of the ground-water might be somewhat as shown by the line *c*, *d*, *e*, *f*, the slopes *c d*, *d e*, and *e f* depending upon the porosity and jointing of the rocks. If those offer comparatively little resistance to the passage of the water, the hydraulic gradients will be much flatter than if the rocks are close grained, and the joints mere lines. If the strata for some height above sea level be very impervious, the percolating water may come to the

surface again above the line *g*, *h*, *i*, *k*, which would then be the upper surface of the ground-water. In some cases the upper surface of the ground-water may correspond almost with the surface of the ground.

It may be, owing to the structure of the ground forming an inverted siphon the longer leg of which is well above sea level, that meteoric water may find its way in large quantities to considerable depths below the surface level of the sea, as we know from observations on artesian wells; that at Grenelle in the Paris basin being 1,798 feet deep, although the surface of the ground at the well is only about 120 feet above sea level. The flow of water from the well is about 600 gallons per minute, and the well at Passy, in the same basin, yields still more.

The circulation of water, along lines of faults and the more or less fractured rocks adjoining them, is readily understood. It may also find easy passage along contacts of igneous and aqueous rocks, whether the former be dykes or sheets, or large intrusive masses; the contraction of the igneous rocks in cooling and the globular vesicles resulting from gas inclusions, form more or less open passages at or near the contacts with the invaded rocks and elsewhere.

Igneous rocks, immediately after cooling, would doubtless contain cracks and partly or wholly unfilled gas cavities such as we see in blast-furnace slags, many of them being as small as the cells of honey-comb or smaller, and sometimes so close together as to interfere with one another. These would, probably, form channels, or help to form channels, for the passage upwards of heated gases and mineral waters. Moreover, breaking through of igneous masses must have severely fractured the adjoining rocks and formed further passages for aqueous circulation.

Circulation along bed-joints, particularly those between different kinds of rocks, may be facilitated by disturbances of the strata during periods of upheaval. Fig. 11 will illustrate the suggestion.

The forcible lifting of the rocks on the upside of the fault *e*, *f* might open the joint *c*, *d* on the opposite, or down side of the

fault, just as the cards in a playing pack, held tightly at one end, are separated when a finger is drawn with a little pressure across the other end. In such a case as that given in Fig. 11 a current might make its way along the slightly opened or shaken joint *c*, *d* for some distance from the fault, then turning to one side or the other, along one or more open cross-joints, might find its way back to the fault at some distance from the point of entry.

The two sets of joints, nearly at right-angles to each other and to the bed planes by which most aqueous rocks are more or less split up, often form important passages for water, particularly in limestone, the joints of which are more open and apparently more persistent than those in siliceous and aluminous rocks, and ore deposits often take place along such joints; in fact the directions of deposits in calcareous rocks are, to a very large extent, determined by those joints, the longer axes of the deposits being parallel to the stronger set of joints.

The circulation which results in hot springs may be due either to the action of gravity, the water having been heated by chemical action, or by contact with heated rocks in its subterranean meanderings, or its ascending motion may have been imparted to it by the solution, in the lower part of the water zone, of heated gases rising from below. The last is most probably the case when the spring contains any of the heavy metallic minerals. The water which burst into the 2,200 feet level of the Savage mine, Comstock,[14] had a temperature of 104° F. Another inrush came from a bore in the Yellow Jacket shaft (about one mile from the Savage) at a depth of 3,080 feet, and had a temperature of 170° F. The outcrop of the Gold and Curry mine, also on the Comstock vein, was 6,400 feet above sea level. The depths at which the two inrushes of water just mentioned took place were measured from a datum on the level of that outcrop, so that, in one case, the water broke into the mine 4,200 feet above sea level, in the other case at 3,120 feet above. The pressures might be hydraulic pressures. The heat might have arisen from chemical action in the adjacent strata, but, seeing that the rocks in the neighbourhood are volcanic and com-

[14]Geology of the Comstock Lode.

paratively young, it is more likely the heat was derived from eruptives of higher temperature below.

The mineral spring in the Einigkeit shaft at Joachimsthal, Bohemia,[15] which was struck at a depth of 1,774 feet, but 675 feet above sea level, is in a different category. It had a temperature of only 73° F., that is, about the same as the rock at that depth. The beds through which it emerged were of sandstone.

Water in rocks much below sea level, if sufficiently heated, would rise to the surface, without any hydraulic head, through suitable channels, at a speed dependent on the temperature and the size of the passages, just as the water in a kitchen boiler rises to the upper part of a four or five story building. Further, water rising from any depth in the earth in this way would be replaced by other water lying in ground adjoining, which, like that rising to the surface, was primarily rainwater; in fact all waters emerging at hot springs (and others) have probably been many times in the clouds.

It is argued by Professor Le Conte, in his criticism of Posepny's "Genesis of Ore Deposits," that it is doubtful whether the pressure of a rising column of heated water with metallic minerals in solution would be sufficient to keep back water in the wall rock. He says: "The ascending water in the fissure is under higher pressure than *precisely similar* water on the outside; for in addition to the hydrostatic pressure determined by the height of the outlet, it is also under hydraulic pressure in proportion to the velocity of the upward current. But the water saturating the wall-rock is also, of course, under heavy hydrostatic pressure. And, when we remember the slowness of the ascending current (which is a necessary condition for deposit) and, therefore, the slight excess of the pressure over that measured by the height of its outlet, and when we remember, further, that the ascending water is *hot*, while the wall-water is *cooler* and, therefore, denser, we may well doubt whether the pressure of the ascending, or the lateral, waters will be the greater and, therefore, whether the current will set outward or

[15]Genesis of Ore Deposits, by F. Posepny.

inward." Professor Le Conte had evidently forgotten that the ascending column carries a quantity of comparatively heavy metallic mineral in solution, and, therefore, that the pressure at any given level would be greater than that of the water in the wall-rock, which has in solution only much lighter non-metallic minerals.

How far below the surface of the earth water exists we do not know, but we do know that the deeper we go, generally speaking, the less there is. In the Przibram District of Bohemia,[16] which is about 1,600 feet above sea level, the deepest adit drains the mines to about 330 feet. Below that the water has to be pumped. The largest quantity comes from the shallower ground, and the amounts raised from the different levels diminish with the increasing depth. At about 975 feet below sea level, or at a depth of 2,575 feet from the surface, there is no water to raise. The air temperature at that depth is about 74° F. which is sufficient to evaporate the small quantity of water there existing in the rocks.

In the Morro Velho mine, in Minas Geraes, Brazil, the only water to be dealt with at a depth of 2,575 feet is that which passes down from the crushed workings above.

The depth to which water descends, generally, will depend upon the character of the rock, the structure of the ground and the orological features. At the Le Roi mine, Rossland, B.C., where the rocks are mainly augite, porphyrite, diorite porphyrite, granodiorite and monzonite, there was no water in the ground to require pumping at a depth of 1,000 feet. But there are a number of strong dykes and faults crossing the vein and leading down the mountainside into the lower ground. These must keep the rocks partly drained. The shaft top is about 3,800 feet above sea level. In limestone districts water often makes its way down to 600 feet and more in large quantities, where the surface is well above sea level.

Daubrée[17] has shown that by capillary action water can make its way down through the interstices of the rocks against an upward pressure, exceeding by 13 lb. per square inch that acting

[16]F. Posepny, Genesis of Ore Deposits.
[17]Géologie Expérimentale, Paris, 1879, p. 274.

on the water downwards. Nevertheless, it does not seem possible that water, even interstitial water, can exist anywhere in faulted ground at a greater depth than about 12,000 feet, for at that depth, or less, the temperature in all probability is such that all water occurring in such ground will be converted into steam. In making this remark it is necessary to say something more as to the circulation of subterranean water. If rocks were all of the same kind and of the comparatively porous character of sandstone that Daubrée experimented with, water might find its way to very great depths—although in the sandstone district of Przibram no water worth speaking of was found at a depth of 3,550 feet—but we know that most aqueous rocks are interstratified by more or less impervious beds of shale or other very fine-grained siliceous and aluminous beds that interfere with the free circulation downwards of underground waters, which most probably accounts for the fact, so often observed in mines, that water cut in working them never comes away from the rocks at anything like the velocity due to the hydraulic head if that be assumed in every case to extend to the surface of the ground-water; in fact, water cut at 200 feet below the surface of the ground-water comes into workings, generally speaking, with a velocity as great as when cut at two or three times that depth, and the enormous pressures supposed by some writers to exist in the deep, do not, in my opinion, really occur. If, at every point downwards, the hydrostatic pressure were produced by a column extending uninterruptedly to the surface, we should find the following pressures:—

Depth Feet	Hydrostatic Pressure lb. per square inch.
100	43
150	64
200	86
250	107
300	129
350	150
400	172

And so on.

A body of water bursting into a mine under a hydrostatic pressure of 172 lb. per square inch must, at first, have great velocity, however the friction of the rocks might affect the hydraulic pressure later and so reduce the velocity, but we never meet with velocities anything like that. Sketch section, Fig. 12, will partly illustrate these remarks.

The rain that falls on the surface will partly sink into the ground through the detrital covering. It will then make its way along the beds of limestone and sandstone—through the joints and interstices—until it is held up by the faults *B* and *C*, which carry more or less impervious matter produced by rubbing off the ends of the shale beds during fault movements, or, it may be that impervious beds on the opposite side of the faults are opposed to those which offer a free channel to the circulating waters. It will therefore be seen that there never can be a great head on the water in any of these beds, as the layers of shale split the ground into a number of separate reservoirs which have no communication with one another. How completely water may be cut off by faults is frequently seen by miners when driving from comparatively dry rocks, like the slate shown in the above section, into the more open and therefore more water-bearing sandstones and limestones dipping towards the fault. Water is found dammed up behind the faults *B* and *C* when they are cut, and is bled off altogether, it may be, or perhaps only in part, depending upon the structure of the ground.

The splitting up of rocks in the way described, it will be seen, accounts for the comparatively small pressures under which water so often issues from the ground in mines. In the case of an unfaulted, or but little faulted, basin, water may occur under great pressure, but that is not likely to be found in a metalliferous mining district where faults and other dislocations of the strata are of most frequent occurrence. This limitation of pressure has an important bearing on some underground heat effects. Let it be assumed that the temperature of the rocks increases below 100 feet at the rate of 1° F. for every 50 feet for 3,000 feet, 1° every 45 feet for 4,000 feet, finally 1° every 40 feet. Starting at 52° 100 feet below the surface, a temperature of 324° will be reached at 12,000 feet. This would convert water into steam

having a pressure of 95 lb. per square inch, absolute. In other words, if the head at that depth does not exceed 186 feet, as it probably would not if confined to one of the beds between the layers of shale, water would be converted into steam. But if the head were 12,000 feet, the water could not possibly be converted into steam at the rock temperature due to that depth, nor could steam be produced at any other depth by the heat of the rocks if the head of water equalled the depth, because the rate at which the hydrostatic pressure increases is much greater than that of the pressure of steam produced by the normally increasing heat downwards, as shown in the following table:—

Depth from Surface Feet	Hydrostatic Pressure lb. per sq. in.	Temperature of Rocks Degrees F.	Steam Pressure at Rock Temperature lb. per sq. in.
100	43	52	..
500	215	60	..
1,000	430	70	..
2,000	860	90	..
5,000	2150	154	4
8,000	3440	224	18½
12,000	5160	324	95

The great heat which we feel sure exists deep down in the earth, far below the water-bearing zone, may at times rise to such a degree that the metallic minerals occurring at those depths may be vaporized, and, rising through the moving faults, the fractures adjoining, and through the shrinkage joints and gas cells of the igneous rocks, may become dissolved in the waters occupying the joints and interstices of the strata at higher levels. That water, carried upward by the heat imparted to it by the dissolved vapours, would pass through the more open ground above and might come into contact with rocks, or might mingle with other solutions, of such composition that they would precipitate the metal in solution, and form one or more deposits of ore along the lines of circulation.

On this view there would everywhere be a very considerable depth between the bottom of the water-bearing zone and the upper part of the barysphere. It would be much greater in some places than in others. Along fault planes and contacts of igneous dykes and necks, water would no doubt descend to much greater depths than in the intervening spaces; the difference being proportional to the distance between the freer passages. At all points variations in depth might result from orological changes.

Some recent writers speak of the vadose waters, i.e., those circulating by gravity, as 'meteoric' waters; those circulated by heat they call 'magmatic' waters. The latter, they assume, are given off by magmas cooling in dykes, sheets, necks, etc. In my interpretation of the facts there is only one lot of water in the earth's crust which can be concerned in mineral deposition —that in the water-bearing zone—which is of variable depth as already explained, and which is put into motion by either gravity or heat, according to circumstances.

Volcanic Emanations.—The materials ejected by volcanoes are of special interest in connection with the present enquiry.

Of vapours and gases by far the most abundant is steam, which has been estimated to form $\frac{999}{1000}$ of the cloud that hangs over a volcano. In estimating the volume of water represented by such a cloud, it is necessary to bear in mind that the volume of steam, at a pressure of one atmosphere, is 1,700 times larger than that of water at the same pressure, and at the height where such clouds form it might be 2,000 times larger.

Dr. C. Daubeny[18] says: "The gaseous exhalations given off by Vesuvius in 1834 and 1845, when I made them the subject of a particular examination, proved to be muriatic acid and aqueous vapour." He further says, p. 607: "The permanently elastic fluids commonly given out are muriatic acid, sulphuretted hydrogen, sulphurous acid, carbonic acid, and nitrogen. Muriatic acid seems to be generated during almost all phases of volcanic action." Again on p. 608: "The solid substances sublimed by volcanoes are: Boracic acid, muriate of ammonia, specular iron ore, muriate of soda, etc."

[18]A Description of Active and Extinct Volcanoes, etc., 1848, p. 236.

The lava which flowed from Vesuvius during the eruption of 1855-6, as it cooled and hardened, gave out successively vapours of hydrochloric acid, chlorides, and sulphurous acid; then steam, and, finally, carbonic acid and combustible gases.[19]

Fouqué[20] ascertained, at Santorin, that hydrochloric and sulphurous acids were only found at points of emission having a temperature above 100° C., while CO_2, H_2S and nitrogen occurred even when the temperature was not higher than that of the atmosphere. He also found that the gaseous emanations contained large quantities of oxygen as well as hydrogen. The results of one analysis were as follows: CO_2 0.22%, O 21.11%, N 21.9%, H 56.7%, marsh gas .07 %.

During the most energetic phase of activity, the vapours given off at a volcanic orifice are chlorine and fluorine. At later and less active stages sulphurous acid is evolved. The final stage of activity is accompanied by carbonic acid with hydrocarbons.

By condensation of sublimed vapours the crevices and adjacent rock surfaces of craters are coated with many substances, including chlorides of sodium, iron, copper and lead, as well as oxides of iron and copper. The following are also met with: ammonium chloride, boracic acid, alum, sulphate of lime, and sulphuric acid.

G. Poulett Scrope[21] says of metallic vapours condensed on the sides of fissures: "The most frequent of these is specular iron. The muriates of copper and iron and the sulphurets of iron, copper, arsenic and selenium are occasionally found in similar situations."

Sulphur vapour and boric acid occur at Vulcano, sulphur selenide being found at the vent. In the fumeroles of Vesuvius, iodine and bromine are detected.[22]

A. Cossal[23] has found in the fumeroles of Vulcano, sodium chloride, ammonia, iron, glauberite, alum, sulphate of lithium,

[19]C. Sainte-Claire Deville & Leblanc. Ann. Chim. et Phys., 1858, p. 19 et seq.
[20]Santorin et ses Eruptions. Paris. 1879.
[21]Volcanoes and the Character of their Phenomena, 1872, p. 143.
[22]R. V. Mattenici, Rend. Acad. Napoii, 1897.
[23]Atti. Acad. Lincei. (3) ii. 1878.

thalium, rhubidium, caesium, hieralite, cobalt, zinc, tellurium, realgar, tin, copper, lead, bismuth and phosphorus.

Sodium chloride appears so abundantly sometimes that large areas on volcanic cones are covered with it.

Chemical Constitution of the Mineral Matter in Underground Waters.—Chemical analysis has shown that all water traversing the rocks forming the earth's crust, carries in solution, more or less mineral matter, that issuing as hot springs carrying the most.

The commonest and most abundant substances are:—chlorides, sulphates and carbonates. The salts in sea water are similar, 30.7% being chlorides, 3.5%, sulphates, and 0.1%, carbonates.

It will be remembered that the commonest gas emanations of volcanoes are chlorine, sulphurous acid and carbonic acid. The following tables of analytical results give the percentages of the different solids obtained in : (1) Water from the 50-fathom level of the Balleswidden mine, Cornwall; (2) Water from the 205-fathom level of the Botallack mine, Cornwall.[24]

	(1)		(2)	
	Grains per Gallon.	Per cent of Residue.	Grains per Gallon.	Per cent of Residue
Calcium sulphate.....	6.8	49.42	22.14	52.45
Sodium chloride.....	5.15	37.42	14.7	34.8
Potassium chloride....	.95	6.9	1.8	4.25
Potassium arsenate....	....	....	Tr	Tr
Aluminum chloride....	Tr	Tr	Tr	Tr
Ferrous carbonate.....	.16	1.16	2.9	6.86
Silica.....	.70	5.08	.7	1.66
Magnesium chloride...	Tr	Tr	Tr	Tr
Carbonic acid.....	Tr	Tr	....	....
	13.76			

[24]J. A. Phillips. Connection of certain phenomena with the Origin of Mineral Veins. Phil. Mag., Dec. 1871.

Other analyses below are of (3) the Einigkeit Spring at Joachimsthal, 1,774 feet below the surface; (4) Water which entered the 1,800 feet level of the Gold and Curry mine on the Comstock vein, Nevada; (5) Water flowing from the quicksilver mine at Sulphur Bank, Lake County, California; and (6) water from Steamboat Springs, Nevada, about 5,000 feet above sea level. Samples 5 and 6 were taken from the surface.

	(3)		(4)	
	Water	Residue	Water	Residue
	%	%	%	%
Alkaline carbonates	.0352	73.9	.0449	54.5
Earthy carbonates	.0055	11.5	..	..
Alkaline sulphates	.0012	2.4	..	..
Earthy sulphates	..	..	.0286	34.7
Chlorides	.0006	1.2	.0020	2.4
Silica	.0051	10.7	.0069	8.3
Other substances	..	.3	..	.1
	.0476	100.0	.0824	100.0
Temperature, degrees F.	73	..	122	..

	(5)		(6)	
	Water	Residue	Water	Residue
	%	%	%	%
Alkaline carbonates	.0325	7.0	.0333	11.7
Earthy carbonates	.0057	1.2	.0017	.6
Alkaline sulphates	.0689	14.8	.0172	6.0
Chlorides	.1115	24.2	.1612	56.9
Silica	.0042	.9	.0391§	13.7
Other substances	.2412*	51.9	.0325*	11.1
	.4640	100.0	.2850	100.0
Temperature, degrees F.	158	..	167	..

* Mostly borax. §Sodium quadrisilicate.

Had the water from which samples (3) and (4) were taken been able to reach the surface, their temperatures would have been lowered in travelling through the rocks between where the samples were taken and the surface. The waters at (4) (5) and (6) came finally through eruptives, (3) through sandstones.

None of the first five waters contains any metallic minerals.

(5) This water contains chiefly carbonates, borates, and chlorides of sodium, potassium, and ammonium; but alkaline sulphides are also present. The gases escaping from the waters are CO_2, H_2S, SO_2, and marsh gas.

In the crevices and pores of the rocks through which (5) comes to the surface cinnabar, occasionally in crystals, occurs, and upon the crusts of cinnabar crystalline aggregates of sulphur appear. According to J. A. Phillips,[25] steam, CO_2 and boracic acid are continually issuing from the springs.

(6) In addition to the substances mentioned in the table, this water was found by Becker[26] to contain HgS, a trace of Na_2S, 1 gramme per ton of Na_2 Sb S_3 and 8.7 grammes per ton of Na_2 As S_3.

In the material occupying fissures at Steamboat Springs, Becker found hydrated ferric oxide, Sb, As, Pb, Cu, Hg, sulphides of gold and silver and traces of Zn, Mn, Co and Ni. The minerals doubtless were deposited by the springs during or immediately subsequent to some period or periods of subterranean disturbance. Mr. Becker says, "Quicksilver in very small amounts is being deposited by the springs now active, together with gold and several other metals, the sulphides which are most abundant in the deposits, are found in solution in the water itself."

The water which broke into the Yellow Jacket Mine, adjoining the mine from which sample (4) was taken, had a temperature of 170° F. and was heavily charged with H_2S according to Becker. The gas liberated from the water to which (5) relates is stated by the same authority to be often ammoni-

[25]Phil. Mag., Dec., 1871.

[26]Geol. Quicksilver Deposits of the Pacific Slope. Monograph Geol. Sur., U.S., 1888.

acal and to consist of CO_2 89.3%, H_2S 2%, CH_4 7.9%, and N 2.5%. From some of the water rising at Steamboat Springs hot vapours and gases—CO_2 and H_2S—still issue.

At other points the gases are so reduced that their escape is only to be detected by careful listening.

In illustration of the varying nature of the waters yielded by mineral springs, the following analytical results[27] of some of the springs in the Yellowstone National Park, U.S.A., are interesting. They give the percentages of the total material in solution.

	(8) %	(9) %	(9) %	(10) %	(11) %
NH_4Cl	.09	.06	1.1	..	.87
$(NH_4)_2SO_4$	..	..	..	83.21	..
Li Cl	.67	.64	1.35	..	..
Li_2SO_4	..	..	..	.11	..
Na_2SO_4	6.94	..	21.46	2.23	5.46
Na Cl	9.13	52.39	47.11	..	..
Na_2CO_3	..	..	..	..	2.15
$Na_2B_4O_7$	1.56	..	1.74	..	1.11
$NaAsO_2$	.20	..	..	..	.
K Cl	4.68	7.29	10.66	..	2.19
K Br	Tr	..	..	..	..
K_2SO_4	..	..	..	.54	.17
As_2O_3	..	.04	.25	..	..
B_2O_3	..	1.72	1.69	1.53	..
Mg Cl	..	.08	..	..	..
$MgCO_3$	..	..	..	..	11.37
$MgSO_4$	17.48	.46	.34	1.78	..
$CaCO_3$	29.99	..	..	..	29.87
$CaSO_4$	9.37	1.82	.45	3.97	..
Al_2O_3	.45	..	.29	..	.67
Al_2C_6	..	.75	..	..	..
$Al_2(SO_4)_3$	..	..	..	.69	..
SiO_2	2.48	31.77	13.05	2.65	1.72

[27]Bulletin No. 47, U.S. Geol. Sur.

	(8) %	(9) %	(9) %	(10) %	(11) %
SO_3	..	..	..	1.05	..
CO_2	16.96	2.22	.51	1.91	44.20
HCl	..	..	..	.18	..
H_2S	Tr	.76	..	.15	.22
	100.00	100.00	100.00	100.00	100.00
Temperature F...	152	163	197	197	64

(7) Cleopatra Spring, Mammoth Hot Springs.
(8) Coral Spring, Norris Geyser Basin.
(9) Chrome Spring, Crater Hill.
(10) Devil's Inkpot, Mount Washburn.
(11) Soda Butte Spring, Soda Butte.

The principal mineral combinations carried by these waters are:—

(7) Carbonate and sulphate of lime, sulphate of magnesia, chloride of sodium and CO_2.
(8) Sodium and potassium chloride and silica.
(9) Sodium chloride and sulphate, silica and potassium chloride.
(10) Ammonium sulphate, calcium sulphate, silica and sodium sulphate.
(11) CO_2, carbonate of lime and carbonate of magnesia, sodium sulphate.

It has been repeatedly shown that solfataras in their first stage of existence give off steam with combinations of fluorine and chlorine, later with those of sulphur, and finally carbonic acid and combinations of hydrogen and carbon. These emanations correspond to those issuing from volcanoes at the corresponding periods of activity.

The frequent and extensive occurrence of chlorides, sulphates and carbonates in mineral waters is doubtless consequent upon the high solubility of their gaseous elements in water, as shown

in the following table, which also gives the solubility in water of H_2S and ammonia for a few temperatures. The quantities are percentages by weight when the partial pressure of the gas, plus the vapour pressure of the liquid at the temperature indicated, is 29.92 inches of mercury.

Temperature	Chlorine	SO_2	CO_2	H_2S	Ammonia
	%	%	%	%	%
50°	.9969	16.21	.2319	.530	68.9
68	.7291	11.29	.1689	.398	53.5
86	.5722	7.81	.1259	....	....
104	.4589	5.41	.0974	....	....
122	.3927	.....	.0762	....	....
140	.3294	.....	.0577	....	....
158	.2792	.....	.....	....	....
176	.2226	.....	.....	....	....
194	.1268	.....	.....	....	....
212	.0000	.....	.....	....	....

As a consequence of decreasing solubility with increasing temperature, none of these gases exists in boiling water, a fact which probably has had much to do with the depth at which mineral deposits have been formed.

Although it cannot be said that any large metallic mineral deposits are forming at the present time, yet it must appear highly probable that if the ascending heated waters of which we have so much evidence contained the necessary metallic elements, they would be likely to deposit some of them on their way through the rocks. At times of violent subterranean activity when the rocks were being rent in twain, new faults being formed and the throw of existing ones increased, passages would be formed, extending deep down into the crust, by which metallic vapours, rising from the barysphere, would become converted into chlorides and sulphates, etc., by the gases dissolved in the waters circulating by gravity through the joints and interstices of the rocks nearer the surface. To this end it is necessary that the gases should be free, and we know from repeated analyses that this is so in many subterranean waters. The fact already

pointed out that the quantity of these dissolved gases is inversely proportional to the temperature has doubtless contributed largely, if not entirely, to the further fact so widely observed of ore deposits becoming less and less downwards, because, the less gas there was in the water, the smaller would be the quantity of metallic mineral taken up and therefore less of it could be deposited. Owing to variations in the containing rocks this reduction may not be quite regular, in fact, for some minor portions of the total depth there may be an increase, but on the whole it is found to hold. The following table shews the maximum percentage weight of chlorine and carbon dioxide that underground waters can carry at different depths and temperatures.

Depth Feet	Rock Temperature Degrees F.	Chlorine %	CO_2 %
900	68	.7291	.1689
1900	86	.5722	.1259
2700	104	.4589	.0974
3690	122	.3927	.9762
4370	140	.3294	.0577
5180	158	.2792	.....
5990	176	.2226	.....
6800	194	.1268	.....
7560	212	0000	.....

The temperatures in column two are those of the rock at the depth given in column one. From this table it is seen that under a pressure of one atmosphere water would be converted into steam at a depth of about 7,560 feet. Under greater pressure as already mentioned (p. 321), the temperatures of steam production would be higher. The above figures make it highly probable—bearing in mind what has been already said about pressures—that all ore deposits produced by chlorides were formed at a less depth than 12,000 feet and that carbonates probably originated still nearer the surface. It would also seem probable that the shallower they were originally, the larger they

are likely to be, other things being equal. Of course, allowance has to be made for denudation subsequent to deposition when considering the original depth.

The minute quantities of metallic minerals sometimes held in solution by subterranean waters do not afford any evidence, in my opinion, that such extremely dilute solutions have produced all or any of our orebodies. On the contrary, it is much more probable that the action of circulating waters on existing ore deposits has helped to produce these weak solutions. The following figures after G. Bischof give the largest amounts of metallic minerals found in springs up to 1854.

	Per ton of water Milligrammes
Arsenious Acid	1 5
Antimony Oxide	.1
Zinc Oxide (sulphate)	13.3
Lead Oxide	.1
Copper Oxide	6.4
Tin Oxide	.1

Cavern Forming.—Caverns in limestone are of frequent occurrence and of all sizes from 'loughs' or 'vugs' a few inches across, to that of the Mammoth Cave in Kentucky. In siliceous rocks they are quite uncommon and never large. Those in calcareous rocks we know are formed by the action of acidulated water along bed-planes and lines of jointing, their longer axes being parallel to the more persistent and more open joints. Some of them are formed entirely in one bed of stone for long lengths, it may be with branches; then perhaps they suddenly step up or down into another bed, or, it may be, a gradual or sudden enlargement takes place both above and below the bed hitherto followed. The breadth of the cavern may be increased at the same time and a large chamber formed. The floor of such a chamber is usually more or less strewn with fragments of limestone of various sizes that have fallen from the roof and sides, and occasionally stalactites and stalagmites are seen in them, but we never see a shale roof. Caverns of this description are

always formed above sea level, so that water containing dissolved lime may be carried off freely to the sea or elsewhere, and so that other water, descending from the surface and acidulated on its way through the rocks, can be brought into contact with the walls of the cavern and effect further enlargement.

Many simple orebodies include cavernous spaces—called by miners in different localities 'loughs' or 'vugs' or 'druses.' They are of various sizes and shapes, and are much more frequent in some orebodies than in others. They are almost always lined with crystalline minerals of different kinds, sometimes in successive layers. Occasionally the same mineral alternates with one or more other minerals. In some cases the various minerals are scattered over the walls of the loughs very irregularly and without any approach to duplication. These loughs are never large, and often so small that the lining, although at most only a few inches thick, almost or quite fills them. Many of the smallest cavities are filled with quartz, even in deposits occurring in calcareous rocks. This kind of cavern may come into existence either above or below sea level.

Posepny, in his "Genesis of Ore Deposits," looks upon what he calls 'Crustification'—that is, the crystallized substances formed on the walls of caverns or druses—as a certain indication that the deposits in which it is found were formed in cavernous spaces, and, on that conclusion, made certain genetic distinctions which really do not exist. Forty-three years ago,[28] and again in 1878, I[29] demonstrated that the hematite deposits of Cumberland and Lancashire were produced by replacement or metasomasis; that, although like caverns in shape, they could not have been deposited in caverns, replacement being a geological necessity. Yet crustification is very common in those deposits, especially in the harder ore, which contains numerous 'loughs' or 'vugs' of various sizes. These loughs are often lined with laminated hematite, often mammillated. Crystals of quartz, calcite, barite and specular iron ore are also found on their walls.

[28]Hematite Deposits of Whitehaven and Furness. Trans. Manchester Geol. Soc., 1875.

[29]Hematite Deposits of West Cumberland. Trans. North of England Inst. of M. & M. E.'s, 1879.

Frequently the mammillated or kidney ore occurs in layers separated by more or less irregular layers of calcite or dolomite. The loughs are a natural consequence of the replacement of limestone by hematite (or siderite), because hematite (or siderite) occupies less space than the limestone by which it was precipitated from the solution which effected the replacement. We have, therefore, in these deposits, clear evidence that crustification, although invariably associated with caverns, does not prove that the deposit in which it occurs was, as a whole, formed in caverns, as Posepny argues. The loughs in which the crustification occurs, in this case, are in the hematite and were formed at the time (not before) the ore was deposited, the crustification being a later formation altogether. In some deposits, where more than one kind of metallic mineral occurs, one or more of them have been deposited in cavities existing in one of the other minerals, which had been formed previously by replacement.

Vein Forming.—Veins occurring in siliceous and aluminous rocks, or in those rocks and interbedded limestones, contain minerals—metallic and non-metallic—which have undoubtedly, to a great extent, been deposited in cellular or cavernous spaces in the siliceous and aluminous rocks that existed prior to the deposition of the ore. Those spaces are usually supposed to have been formed by differential movements of the rocks intersected by fault-planes, as illustrated in Figs. 13 and 14, the former showing a supposed line of fracture before differential movement, and the latter, spaces *a*, *b*, *c*, supposed to have been formed by an upward movement of the footwall *A*, as indicated by the arrow. They are called by Posepny spaces of diascission.

Widenings and narrowings like those shown in Fig. 14 are, however, found in veins where there has been little or no differential movement, as in some of the lead veins of Alston Moor in Cumberland, in which the orebodies are much wider in the limestone beds than in the alternating sandstones. In such cases the widenings have clearly arisen from some circulating solution acting more freely on the calcareous than on the siliceous rocks. In Wheal Alfred, near Gwinear, Cornwall, there was

conclusive evidence that widenings of a vein occur where there has not been the least differential movement of the vein-walls as shown in Fig. 15.

Regarding this section, Sir H. de la Beche[30] says: "The Elvan dyke *a*, *b*, is about 300 feet thick. The lode *c*, *d*, traverses the Elvan obliquely, in its descent at *e*, *f*. This lode produced some ore whilst in the slate, but upon entering the Elvan *a*, *b*, it became much richer. After quitting the Elvan at *f*, and upon entering the slate or Killas *f*, *d*, the lode became poor. The width of the lode was from 6 to 9 feet in the slate above the Elvan, increasing in the latter to 25 feet, but decreasing in the slate beneath to 10 feet." It is quite clear from the uninterrupted course of the Elvan that there has not been any differential movement of the vein walls.

Many other instances could be given of the widening and narrowing of veins in siliceous rocks where there has not been any differential movement of the walls. Some of these are mentioned in the writer's paper on the "Mineral Veins of the Lake District."[31]

Nearly all writers on mineral deposits have dealt with veins as if they were filled fissures, and have called them 'fissure-veins.' Had they been such we should have found, in those that came to the surface, all kinds of detrital matter—clay, sand, gravel, boulders, and other extraneous matter—as well as large and small fragments from the hanging wall. The last two would have been found in all veins, for it is impossible that the hanging walls could have remained intact over the large areas of some of the ore-shoots during the time necessary to deposit the vein-materials. Miners have often the greatest difficulty in keeping up these walls whilst the ore is being extracted. In every case, veins must have been preceded by fractures of the rocks, often by fault-planes, but never by fissures, that is to say, open fissures having the same width as the subsequent orebodies. Veins very often have one wall regular—being a fault-plane—the other very irregular. This would not be if veins were filled fissures. Again, the ore-bearing portions of many veins do not

[30]Geology of Cornwall, Devon and West Somerset, 1839.
[31]Trans. Manchester Geological Society, 1884.

come to the surface, a circumstance opposed to the fissure idea. The apex of the Eureka-Idaho shoot, California, is 100 feet below the surface, and the upper part of the main shoot of the W.Y.O.D. vein in the same district is several hundred feet down.

Siliceous and aluminous rocks, in which veins mostly occur, vary both in composition and in hardness, and it is a common observation in mines that, in the same vein, when in such rocks, the ore is, as a rule, wider where the rocks are soft than where they are hard. This, no doubt, is due to the softer rocks being more easily acted on by acid or other solutions, and not to any differential movement of the rocks. Variations in the width of a vein may also be due to some change in the mineral composition of the enclosing rocks.

If silicate rocks were acted on by an acid or other solution in such a way that the alumina, iron, lime, magnesia and alkalies, or part of them, were removed, leaving the insoluble silica behind, spaces would be formed in the wall rock, adjoining the fault-plane, in various directions and of various sizes (to a large extent following the jointing) the acid or other solution acting on the rocks more or less freely according to the mineral and physical character of the latter. It is very probable that, in some cases, the silicates of lime and magnesia in the rocks were acted on by an alkaline carbonate, and carbonate of lime or dolomite precipitated in place of the silicates. The calcite or dolomite, or part of it, or them, might afterwards be replaced by one or other of the metallic minerals. There is no doubt that much of the ore occurring in the veins in silicate rocks came into being as a replacement.

In the mode of action just described, inclusions of the country rock would be formed such as we see in most veins, and the ramifying spaces, contracting and expanding, and partly filled with the residue of insoluble silica, would be ready to receive more silica or other non-metallic minerals, or one or more of the metallic minerals in succession, just as we know the different minerals found in ore deposits have been introduced, even the same kind of mineral having been formed at two or three more or less widely separated times. In this way the formation of

cavernous spaces, and replacements by non-metallic minerals, may not have been completed at one period, but may have been extended again and again at times far apart, even after some of the first-formed spaces had been partly or wholly filled with vein-matter or with some metallic mineral, and the strings and bunches of the first-formed calcite and dolomite had been wholly or partly replaced by metallic minerals. In no other way does it seem possible to account for the correspondence of the rock inclusions found in veins to the wall rock (if both walls are of the same kind of rock), and to the rock on the side of the irregular wall, if the wall-rocks are different. The regular wall is, perhaps, always a fault-plane along which the acting solutions have circulated, but, being frequently coated more or less with an impervious 'gouge' or 'flucan,' was protected to some extent from the decomposing or dissolving action of the mineral waters, the repeated differential movements keeping the gouge replaced if it should be removed. In support of this view of the origin of rock inclusions, generally, it may be recalled that, whenever there is any distinct bedding in the wall rock, it is also to be found in the inclusions, parallel to the former, which it would not be if the inclusions had been broken from the hanging wall and had fallen in to spaces such as are supposed by many writers to have been produced by differential fault-movements, as illustrated in Fig. 14. Whenever a fault-plane forms the hanging wall of a vein, no part of it has ever fallen into the vein space, as it certainly would have done if there had been the large open spaces which the fissure-vein idea requires. This regular and unbroken character of the fault-plane, in such circumstances, is conclusive against the assumed open fissures.

Horses of rock, like that in Fig. 16, could not be formed by differential movements of vein-walls, but on the suggestion made above might be expected to occur.

I first made the above suggestion in a paper on "The Mineral Veins of the Lake District,"[32] and again in the "Silver-lead Deposits of the Slocan, British Columbia."[33] In the latter the following passage occurs: "Let us suppose for a moment that

[32]Trans. Manchester Geol. Soc., 1884.
[33]Trans. Inst. of Min. and Met., 1899.

all the metallic minerals, all the quartz, and other xenogenous non-metallic minerals occurring in any of the Slocan veins. were removed. Should we have a fissure left ? No. We should have a complicated network of cavities traversing the altered country rock in all directions (within the vein space) and varying in width in the different chambers, and often even in the same chamber, from narrow joints, the sides of which are almost touching, to spaces 5 or 6 feet wide; varying also in length and depth in the several chambers from a few inches to 40 or 50 feet"; and again: "An entire removal of all the minerals, except quartz, must result in the production of cavities. They may afterwards be filled by other quartz or by metallic or non-metallic minerals. If vein-quartz originated in this way, we understand at once why it is absent, or nearly so, from deposits which have replaced calcareous rocks." As bearing on the above suggestion as to the origin of vein-quartz two analyses by J. A. Phillips of the unaltered and altered slate from the neighbourhood of Lincoln, in Placer County, California, and of the quartz in the Katie Hayes vein, Grass Valley, California, are of special interest. The unaltered rock had a specific gravity of 2.55, that of the altered rock was 2.50. Their composition was as under:—

	Unaltered Rock %	Altered Rock %	Vein-Quartz %
Water lost at 212° F.	.31	.11	.26
" by subsequent ignition	1.88	Tr	.70
Silica	72.05	93.33	93.32
Alumina	17.87	4.46	2.03
Peroxide of Iron	1.98	Tr pyrite	1.29
Sulphur	.....	.....	1.45
Lime	1.65	.75	Tr
Magnesia	.38	.43	Tr
Potash	1.71	.52	.40
Soda	2.40	Tr	.21
	100.23	99.60	99.66

Mr. Phillips[34] says of the altered rock, "When examined under the microscope this substance appears to consist of the siliceous skeleton of the auriferous slate from which the aluminous and ferruginous matters have been almost entirely removed. The angular fragments of quartz, being thus deprived of the cementing material which originally bound them together and gave solidity to the mass, remain in a disintegrated and friable state, although still retaining distinct indications of stratification." The earths in the altered rock are higher than in the vein-quartz, otherwise there is not much difference and a little more exposure to the solution that produced the alteration might have completely eliminated the difference.

The 'comb' structure and duplication of mineral incrustations on the opposite walls of small parts of some veins, which are given undue prominence in some geological text-books, are probably produced by the deposition of mineral matter on the walls of cavernous spaces originating by the action of decomposing solutions as described above. The repetition of combs as seen at Wheal Julia, near Binners Down, Cornwall, and shown in Fig. 17, probably results from successive widenings by dissolution of the materials in the vein-space at those particular points, the clay forming the partings of the different combs being probably introduced as a deposit on the walls of the separately formed spaces, as we often see it on the walls of existing caverns. These partings cannot have been produced by abrasion, or the comb structure would have been destroyed; moreover, the abrasion of quartz would not produce clay. Nor is it possible that the successive widenings of the vein-space could have been produced by differential movements of the walls. The curved clay parting *e* makes it quite clear that there cannot have been any differential movement vertically along that line, such as is assumed by some writers. Further, if these combs had been formed in spaces produced by successive widenings of the vein by movements of the walls outwards they would have occurred from the surface downwards, but they do not, being usually quite limited in extent both vertically and lengthwise of the vein.

[34]Notes on the Chemical Geology of the Goldfields of California, Phil. Mag., Nov., 1868.

The cavernous spaces in siliceous and aluminous rocks having been formed in the way described, it is clear there would never be any large area of the hanging walls without support, and therefore it could not fall away in large pieces, as it assuredly must have done if the vein-space had been produced, as is generally assumed, by a differential movement of the foot and hanging wall. Small pieces might, and we know did, fall from the walls of some of the larger spaces and were afterwards cemented together by metallic or non-metallic minerals, but, as I said in the "Mineral Veins of the Lake District," when dealing with the open fissure suggestion, "One of the first objections that must rise in the mind of every miner is the impossibility (so far as his experience goes), of the walls remaining intact and apart whilst the vein matter was being deposited. This difficulty can only be properly appreciated by those who are acquainted with vein-mining, and who therefore know the great tendency of vein-walls to close together, and also the liability of the hanging wall to break and fall away."

Veins vary in width, and the metallic minerals frequently occur in irregular patches which vary greatly in form and size. Some of these are spoken of as shoots, others as bunches or as chimneys. There may be few or many shoots or bunches in a vein, separated from one another by more or less barren or unpayable ground. These shoots and chimneys have sometimes what miners call a 'pitch'—in other words, they have a dip lengthwise on the vein, and when such is the case it is found that the pitch corresponds with the dip of the strata forming one or both of the walls, or with pronounced sheeting. Differential movements of walls could not produce effects of this kind. They are clearly due to the mineral solutions which formed the deposit having acted more freely on the rocks, forming one or both of the walls of the shoots, than on other parts of the walls where the veins are narrower, or where, it may be, the vein material is pinched out entirely.

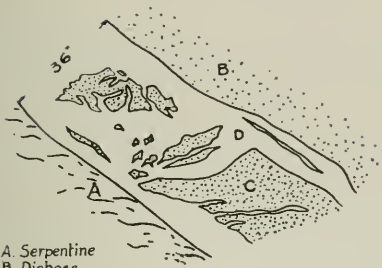
The acid or other solution which removed the alumina, the alkaline earths and the alkalies from the rocks within the vein-space, where the circulation was more or less free, would act in a similar but much more restricted way on the vein-walls—out-

side the completed vein-space—and so we find they are altered for a certain distance on each side of the veins, in a diminishing degree as the distance from the vein increases. Veinlets of quartz, which are of frequent occurrence both within the vein-space and in the country rock adjoining appear to have been produced in a similar way, that is by acid or other solutions removing the earths and alkalies and leaving the silica. I have examined a large number of such veinlets under the microscope, and have always found them to graduate into the rocks they traverse.

The above seems to be the most reasonable explanation of such sections as those exhibited in Figs. 18, 19, 20, and 21, which are given as illustrative of vast numbers of others that have been seen in veins traversing silicate rocks. Fig. 18 is a vertical section in the Maryland vein, Grass Valley, California, after W. Lindgren.[35] Fig. 19 is a horizontal section of part of the Poorman gold-bearing vein, near Nelson, British Columbia.

Fig. 20 is a section of the Corinth vein, Slocan District, British Columbia, from my paper on the "Silver-lead Deposits of the Slocan."[36] Figs. 21 and 22 are microscopic sections of ore from British Columbia. The former is copper ore from the Silver King mine, Nelson; the latter from the War Eagle mine, Rossland. Both are taken from my paper on the "Auriferous and Argentiferous Copper Ores of Southern British Columbia."[37] I have seen similar sections in almost every vein I have examined in many parts of the world. In Fig. 21 the altered country rock is seen to be more or less broken up by irregular strings, spots and bunches of quartz and felspar which have a more or less graduated connection with the altered country rock and appear to have originated from a further alteration of that rock, some of its constituent minerals having been removed whilst the quartz and felspar were left behind. Such an extreme alteration would produce a number of cavities which might afterwards be filled by the chalcopyrite. Casts of quartz crystals are frequently met with in the bornite, tetrahedrite, etc.

[35] U.S.A. Geol. Sur., 1895-6.
[36] Trans. Inst. of Min. and Met., 1899.
[37] *The Mining Journal*, 1900.



A. Serpentine
B. Diabase
C. · decomposed
D Quartz

Fig 18.

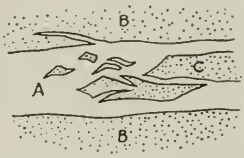


Fig 19

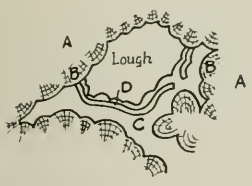
A. Quartz
B. Mica Syenite
C. do. decomposed

A. Argillite
B Galena & Limonite
C Calcite & Quartz

Fig 20.

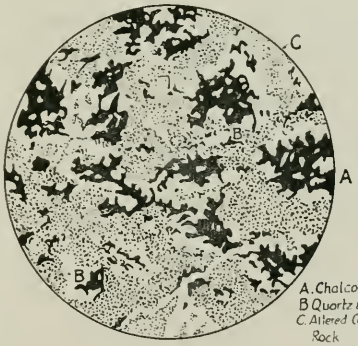
A. Pyrrhotite & Chalcopyrite
B. Altered Country rock
C. Quartz.

Fig 22 x 10 Linear



A. Massive Hematite
B Kidney Ore
C Brown Spar
D Laminated hematite

Fig 23



A. Chalcopyrite
B Quartz & Felspar
C Altered Country Rock

Fig 21 x 10 linear

To me it is inconceivable that a network of metallic mineral in rock, such as is shown in Figure 22, can have been produced otherwise than by substitution, yet such occurrences are frequently met with, especially in silicate rocks.

The quartz in the saddle and inverted saddle-reefs of Bendigo, Queensland, most probably owe their existence to the action of

acid or other waters on the ruptured beds along the anticlinal and synclinal axes of the folded strata. The gold was probably introduced through the faults and dykes that intersect the strata.

Classification of Ore Deposits.—Ore deposits are of many different kinds, but a satisfactory classification of them has not yet been arrived at. In the early days of enquiry 'form' played an important part. In more recent years a genetic classification has been sought, but unsuccessfully, and with much complication. Until we are agreed as to the genesis of the different kinds of deposit, we shall be unable to classify them from such a standpoint. But even if such a scheme were arranged, it might frequently be impossible to classify newly-discovered deposits unless their genesis could be determined immediately, which might not be possible. The recent trend of thought is toward simplification. Later it may be found that genetic differences are so small and so obscure as to form a poor basis of classification. There is nothing in them akin to, or comparable with, or which can replace, the genealogical relations pervading biological and geological classifications, or the chemical and mineralogical differences of the various plutonic and volcanic rocks.

In the present state of knowledge the most useful features to employ in classification appear to be those of form and structure. They are not as definite as could be wished, but they are easily recognized. The first division which may be made has reference to the manner in which the metallic minerals occur in the deposits. Some, like iron and manganese, practically form the whole of the workable part of a deposit. These may be called 'simple' or homogeneous deposits; others, like gold, silver, tin, copper, lead and zinc, etc., occupy but a portion, sometimes but a very small portion, of the deposit, the bulk being non-metallic gangue such as quartz, calcite, dolomite, barite, etc., or inclusions of country rock. In these deposits two or more principal minerals occur. They are scattered through the gangue in detached portions of varied form and size, sometimes as mere specks, or even in microscopic quantities. The total amount of the metallic

minerals, as well as the size of the separate portions, is very much less in gold, silver and tin than in those of copper, lead and zinc. In the gold veins of the Grass Valley and Nevada City districts of California, the metallic minerals, including gold, silver, pyrite, chalcopyrite, galena, blende, etc., are only 1 to 6 per cent of the vein contents, generally 2 to 3 per cent, 80 to 90 per cent of the aggregate of such minerals being pyrite. Such deposits may be called 'mixed' or heterogeneous deposits. Both simple and mixed deposits may be further divided as under.

Primary Deposits:—

(1) Veins: Steeply inclined in most cases, of great length and depth compared to their width, and usually cutting across the beds in stratified formations, but occasionally conforming thereto, if the fault-planes along which they occur are parallel to the bed-planes of the strata.

(2) Beds: Layers of mineral matter interstratified with the accompanying rocks, including such occurrences as the saddle reefs of Bendigo. They may be fairly uniform in thickness or more or less lenticular. Lake and bog deposits may be looked upon as beds in the making.

(3) Irregular Deposits: Including all cavern-like masses of mineral, whether occurring along contacts of rocks of different kinds, or surrounded entirely by rock of the same kind, and all such bodies as stocks and impregnations.

Secondary Deposits:—

Placers—Produced by the breaking up of primary deposits, such as the alluvial deposits of gold and tin.

Beach Deposits—like magnetic sand.

The manner in which the metallic minerals occur in mixed deposits may be:—

(a) Interstitial—in the interstices of sands, gravels, conglomerates and breccias. Like the copper deposits of Huin-Quintipa in Chili, or the banket gold of the Rand, S.A.

(b) Reticulated—occurring in gangue or associated rock as irregular network, like stockworks and the chalcopyrite in Fig. 22.

(c) Disseminated—scattered through the associated rocks in nodules, flakes or granules, like the lead ores of Missouri, or graphite in gneiss.

(d) Diversified—scattered through the non-metallic gangue and rock-inclusions in such a way that, sectionally, they appear as spots, blotches, strings and ribs, like the lead ore in Fig. 45.

A body of magnetite or hematite would, under such an arrangement, be a simple deposit occurring as a vein or bed, or in an irregular form.

A deposit of lead ore with blende would be a mixed vein, bed, or irregular body, according to its form; and reticulated, disseminated, or diversified, depending upon its particular internal habit.

A deposit of auriferous and argentiferous copper ore would be similarly described.

The first part of this classification corresponds largely to that of Von Cotta and Prime.[38] A. Von Groddeck's[39] classification is more genetic, but it labours under the disadvantage that the origin of many deposits is in doubt.

Posepny,[40] in search of a genetic principle, first divides deposits into those that are contemporaneous with the country

[38]Ore Deposits. New York, 1870.
[39]Die Libre von den Erzlagerstätten der Erze. Leipzig, 1879.
[40]The Genesis of Ore Deposits. New York, 1895.

rock, and those subsequently formed in it. We meet here with a difficulty at the beginning. Some ore-beds that are usually looked upon as contemporaneous deposits I hope to be able to show, in the sequel, were formed subsequently, being replacements.

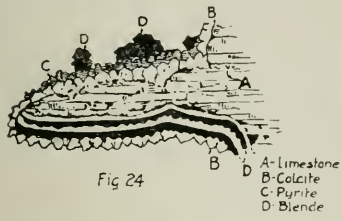


Fig 24

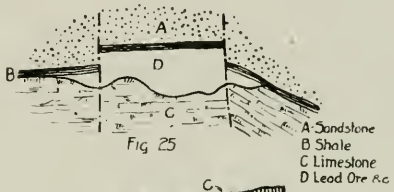


Fig 25

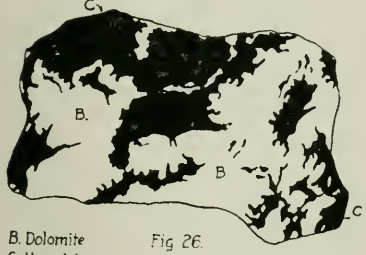


Fig 26.

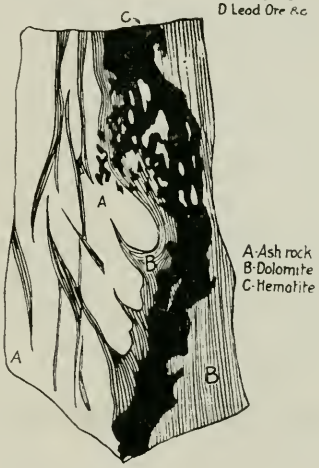


Fig 27

Fig 29

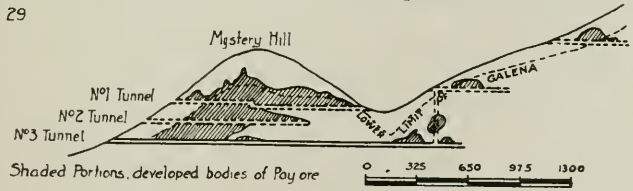


Fig. 28.

Order of, and Repetition of, Deposits.—The bulk of any 'simple' ore-deposit was almost certainly formed at one period, however short or extended that might be, but we have abundant evidence that the metallic minerals occurring in such ore-

deposits have been formed at two or three different periods, some of them probably in a small way only, and separated from one another by the time required to form an intervening layer of non-metallic minerals, such as is shown in Figs. 23 and 24, to give two instances only. It may, of course, be that these later deposits were the result of solution and re-deposition.

Fig. 23 is one of many such occurrences that may be seen in the hematite deposits of West Cumberland and North Lancashire. Fig. 24 shows similar repetitions of ore-forming in the lead deposits of Alston Moor.

We also find on the walls of the ore-loughs in the hematite mines of Cumberland:—

(a) Crystals of quartz on hematite and crystals of specular iron ore on the quartz crystals.

(b) Specular iron ore on brecciated 'shells' or layers of mammillary hematite cemented together by calcite.

In 'mixed' orebodies, such as those of copper, lead, and zinc, etc., nearly the whole of any one mineral was, in all probability, deposited at one period, but we have evidence that two if not more depositions took place, at times, it may be, separated by considerable intervals.

In the lead veins of Alston Moor we find the following among other evidences of repeated deposition of pyrite, blende and galena:—

(1) Crystals of blende on massive pyrite, crystals of dolomite on the blende crystals, and crystals of pyrite on both the blende and dolomite crystals.

(2) Crystals of galena (1) on crystals of calcite (1) and crystals of calcite (2) on the galena crystals (1). On the calcite crystals (2) other crystals of galena (2) occur, and on these more crystals of calcite (3).

(3) Crystals of fluorite on crystals of galena (1) crystals of quartz on the fluorite and crystals of galena (2) on the quartz crystals.

(4) Crystals of dolomite on crystals of blende and crystals of blende on the dolomite.

The various minerals in a 'mixed' deposit were clearly formed at different times, the metallic and non-metallic minerals sometimes alternating. In some instances two or more metallic minerals appear to have succeeded one another without any non-metallic mineral intervening. In the district from which the above evidence was obtained, the paragenesis, or order of succession, of the metallic minerals appears to have been—siderite or pyrite, blende and galena. Of the non-metallic minerals the order of introduction has, in some cases, been—fluorite, quartz, calcite. In some of the lead mines of British Columbia the order of introduction was siderite, blende, galena. The lead deposits of Leadville, Colorado, present a similar order of deposition, the blende and galena having been preceded by a huge deposit of iron ore.

In 'mixed' deposits in the siliceous rocks the metallic minerals appear to have been formed partly in spaces left within the quartz gangue, or between the quartz and the country rock, and partly by the replacement of some other mineral, perhaps calcite or dolomite, which had partly replaced the silicate of lime, as follows: — $CaSiO_3 + Na_2CO_3 = CaCO_3 + Na_2SiO_3$. The additional $CaCO_3$ needed to fill the space produced by the removal of $CaSiO_3$ might be provided by the action of Na_2CO_3 on $CaSO_4$ contained in the water circulating through the vein-space. Similar action might take place on the silicate of magnesia. The result of these actions is seen in the increased quantity of lime in the altered wall rocks of many mines. Below are given results obtained in two Californian mines.

	Unaltered Wall Rock	Altered Wall Rock
	%	%
North Star mine.....	9.39	23.85
Federal Loan mine.....	2.47	11.10

Where the cavities in the quartz were small and numerous, the metallic minerals in them give the veins quite a spotted appearance, as in Figs. 38, 41 and 42. There is, perhaps, not any regular order of formation of the different metallic minerals

in every mining field, but it is remarkable how very often quartz or iron ore appear to have been the first formed. It is probable that quartz was, in every case, the first mineral to appear in the veins that are in silicate rocks, and that where iron ore or other mineral appears attached to the wall rock it was because quartz, although first formed, had not everywhere covered the country rock, as might easily happen. 'Mixed' deposits in calcareous rocks were often, if not always, initiated by pyrite or siderite, the galena and blende, or chalcopyrite, or other mineral, following and forming partly in the cavities of the iron ore resulting from the reduction of volume consequent upon the replacement of limestone by pyrite or siderite. This was the case to a large extent at Leadville, and in all the lead deposits occurring in the limestones of the Great Basin of America and elsewhere, limonite (altered siderite), being the characteristic gangue. Copper deposits in limestone seem in some cases to have had a similar origin—limonite in the altered zone forming a large part of the gangue.

Primary and Secondary Minerals.—When we get below the zone of alteration we find that some metallic minerals, such as those of copper, lead and zinc, etc., occur as sulphides. Others, like some hematite, some manganese ores, tungstite and cassiterate, were deposited as oxides. Such sulphides and oxides may be appropriately looked upon as primary ores. Other ores, such as the oxides and carbonates of copper, the carbonate and phosphates of lead, and the hydrated oxides of iron, to mention only a few, are alteration products, and may be consequently looked upon as secondary ores. Limonite, for example, may be produced by the alteration of either pyrite or siderite, or from the hydration of hematite, but it occasionally occurs as a primary ore when deposited by organic agency.

The secondary minerals are all found in the upper parts of orebodies, when both primary and secondary ores occur in the same deposit. They were doubtless produced by alteration of the primary ores through the agency of oxygenated or acidulated water circulating by gravity. When secondary ores are found almost alone in a deposit they must have been preceded

by primary ores. The cerussite deposits of the Organ and Magdalena Mountains of New Mexico are simply alterations of galena. In some copper deposits which, in the deep, contain only sulphides of copper and iron, we find for some depth below the surface—called the zone of impoverishment—very little copper, and that either in the metallic state or as red or black oxide. The iron occurs as hydrated oxide with occasionally some hematite. Below the zone of impoverishment we find a belt of ground known as the zone of enrichment in which the copper occurs chiefly as carbonates (malachite and azurite) or the higher sulphides. The copper which was originally deposited in what subsequently became the zone of impoverishment has been dissolved and re-deposited in lower ground—the zone of enrichment—alongside the ore already existing there, and which, at the same time probably, was also to a greater or less extent altered from sulphide to carbonates, whilst the accompanying iron sulphide was mostly changed into hydrated peroxide.

The upper part of Mount Morgan gold and copper deposit in Queensland, from which the copper had been leached, was worked for gold only for some years, and some of the silver-copper veins at Butte, Montana, similarly denuded of copper, were worked as silver mines in their upper parts. At Bingham in Utah, and Ely in Nevada, similar modifications have been effected in the upper parts of the deposits.

In the upper parts of deposits, containing galena, blende and pyrite below the ground-water level, we find limonite, cerussite, pyromorphite and wulfenite resulting from the alteration of pyrite and galena. The blende on being changed to sulphate disappears, being carried off in solution.

The non-metallic minerals, of which the gangue of a large proportion of ore-deposits is mainly composed, do not alter with depth. They are mostly silica, calcite, dolomite and fluorite. Barite and witherite also occur as gangue minerals; they have a much higher specific gravity than the others and not improbably were introduced into ore-deposits from below during periods of plutonic activity, witherite being an alteration product. The other non-metallic gangue-minerals, silica, calcite, dolomite and

fluorite, in all probability were derived from the enclosing rocks. It will be noticed that there is not any barium in analyses (1), (2), (7)), (8), (9), (10) and (11). Nor is there any in the waters coming from the nine springs of Carlsbad. In the analytical results of the water of 787 springs in U.S.A.[41] only 31 contain any barium. Of these 24 had less than 1 grain of barium salt per gallon. Mostly they contained only traces.

Influence of Country Rock.—The frequent occurrence of cassiterite in granite is suggestive of there being something in the rock which has caused the precipitation of that ore from circulating solutions. But, if that be so, the same substance must exist in other rocks occasionally, in the necessary quantity and condition, for in Mexico we find cassiterite in trachyte, and in Bolivia it is said to occur in diorite. Below, in column A, is given the mean of the results of 11 analyses of granite by Dr. Haughton; under B, the composition of eurite, or fine grained elvan. C shews the chemical constitution of trachyte.

	A	B	C
	per cent	per cent	per cent
SiO_2	72.07	71.46	62.39
Al_2O_3	14.81	15.38	20.23
Fe_2O_3	2.22	.30	..
FeO	..	2.27	5.32
K_2O	5.11	5.51	5.76
Na_2O	2.79	2.79	3.90
CaO	1.63	.47	1.09
MgO	.33	.22	.86
Loss on Ignition	1.09	1.70	2.02
	100.05	100.10	101.57

It is probably owing to the comparatively large amount of potash in the granite that tin oxide is so often found in that rock. A similar or larger amount of potash occurs in the Cornish elvans, which are so frequently tin-bearing. Trachyte is also

[41]Geol. Sur., U.S.A., Bulletin 32.

rich in potash. The average amount of potash in the Killas (clay slate) of Cornwall is only about 1.39 per cent.[42] The tin mines of Wheal Vor and Great Work, near Breague, Cornwall, may be mentioned in this connection. De la Beche[43] says at both mines: "The fissures forming the lodes traverse the same granite and slate, are nearly parallel to each other, and are only a mile apart; yet at Wheal Vor the lode, which contained so much tin ore in the slates, held so little where it entered the granite, as not to be worth working, while at Great Work the lode which was so rich in the granite became worthless after it entered the slates. The principal difference in the two mines is that elvan was traversed by the lode at Wheal Vor, while in the slates, which did not happen in the slate near Great Work." Really the lode at Wheal Vor was in the elvan. The influence of elvan in inducing a deposit of cassiterite is further shown by the facts exhibited in Fig. 15.

It is known that water under high pressure and temperature has the power of decomposing orthoclase[44]—the felspar of granite and eurite—and obtaining from it potash in solution. Orthoclase contains about 12% of potash. This, it would seem, has an important bearing on the formation of tin oxide, as will be seen later. J. A. Phillips,[45] writing on this subject in reference to deposits in Cornish granite, says: "If the enclosed crystals of felspar have a greenish or pinkish tint, with indistinct outlines merging into the ground mass, quartz, mica and sometimes schorl being present, the character of the rock is considered to be a favourable one, and lodes enclosed in it may be expected to be fairly productive, especially of tin-ore." The indistinct outlines of the orthoclase and their merging into the groundmass may be due to the abstraction of some of the potash from the orthoclase as above suggested.

I do not know of any other mineral that exhibits such a marked preference for a particular description of rock. As

[42]Rocks of the Mining District of Cornwall, by J. A. Phillips. Quart. Journ. Geol. Soc., Vol. XXXI, p. 322.
[43]Geol. of Cornwall, Devon and West Somerset, p. 328.
[44]Forchhammer—Poggendorff's Annalen, XXXV, 353.
[45]Ore Deposits, p. 62.

already stated, cassiterite occurs in other rocks than granite, as for example, in the Killas or clay slate of Cornwall, but there the slate is in close association with either granite or elvan.

Galena and its alterations occur frequently in limestone, but it cannot be said there is anything like the preponderance of such deposits in that rock as there is of cassiterite in granite. Gold is rarely found in calcareous rocks, and the silicate rocks in which it is found contain very little, sometimes scarcely a trace, of lime.

The silver veins around Freiberg are in gneiss—traversed by igneous dykes—passing into mica-schists with beds of limestone. The gneiss of the Erzgebirge is partly grey and partly red. The former contains 64 to 67% silica, the latter 74 to 76%. According to V. Cotta[46] and Muller the grey gneiss is more favourable to ore-deposits than the red, which contains comparatively few metalliferous veins. It would seem that the less amount of silica is the favouring factor.

The veins at Silver Islet mine, on Lake Superior, are partly in unaltered flags and shales, and partly in a large diorite dyke. Where the latter forms the walls the vein carries native silver and sulphides of lead, nickel, zinc., etc., but where flags form the walls the vein carries calcite only.

The veins of Kongsberg, Norway, which carry silver in the fahlbands, are doubtless illustrations of the influence of country rock. The fahlbands are parallel in strike and dip to the gneissose and schistose rocks in which they occur. They are impregnations of finely divided pyrite, chalcopyrite and blende, with occasionally galena, silver and cobalt. They are intersected by veins which carry silver and other ores, but the veins are most productive when crossing the fahlbands.

In every mineral deposit there was, doubtless, some feature in the physical or chemical character of the country rock which determined, to a large extent, the precise locus of the deposit. Now, it is not possible, in many cases, to offer more than a suggestion as to what that determining factor was, because, in the formation of the deposit, it has been removed.

[46]B. Cotta and H. Muller, "Grangstudien," vol. 1, 1850, p. 209.

Pseudomorphs.— Pseudomorphs may be looked upon as pointers along the road followed by Nature to the present stage of evolution. There are several different kinds, but we are here mainly concerned with those produced by substitution, as for example:—

Cassiterite,	after orthoclase.	Silver,	after calcite.
Galena,	" calcite.	Quartz,	" "
Calamine	" "	Blende,	" dolomite.
Pyrite,	" "	Pyrite	" "
Hematite,	" "	Hematite,	" fluorite
Limonite,	" "	Chalcedony,	" "
Pyrolusite	" "	Hematite,	" "
		Quartz,	" barite.

Natural processes are not limited to one line of action, but we have here proof of changes that have been effected in a certain way, and it is quite possible that what is exhibited in these crystals, on a small scale, may have taken place on a much larger scale with these and other minerals as well, and in that way have produced a large proportion of our simple and mixed orebodies. Deposits in calcareous or dolomitic rocks were probably all, either to a large extent or entirely, produced by the substitution of one or more of the metallic minerals they contain for carbonate of lime or dolomite. The precise manner in which the replacement was effected may never be known, but for the replacement we have geological evidence, in many cases, which cannot be doubted, and which is quite independent of any chemical considerations; as, for example, in the thin shale partings which occur in the hematite deposits of West Cumberland[47] and Furness[48] and in the shale roofs of some of those deposits.

Shale forms the roof of parts of the deposits in the blue limestone of Leadville and in the same district shale partings, which are interbedded with the lower layers of the white limestone, continue through the ore-deposits of that horizon, as seen

[47]Hematite Deposits of West Cumberland, by J. D. Kendall.
[48]Hematite Deposits of Furness, by J. D. Kendall.

in the Tucson Mine. Similar shale partings—interbedded with the limestone of Black Hills, South Dakota—pass through the deposits of auriferous quartz which have replaced the limestone. A bed of shale formed the roof of the lead deposit worked by the El Capitan mine[49] about 8 miles north of Leadville, also of that worked by the Robinson mine on Ten Mile Creek, Colorado, as shown in Fig. 25. The slaty roof of the Elkhorn silver-lead mine in Montana shows that it also was formed by replacement, and not in a cavern, the roof being very difficult to keep up in working the ore.

We have in Fig. 25 evidence not only of replacement of limestone by ore, but also that the replacement was effected after the faulting. The two faults shewn in the section intersect the overlying shale bed and cause that part of it between them to be higher than the outlying portions, but they do not similarly affect the lower part of the ore-deposit as they would have done if they had followed the deposition of the ore. An interesting point arises in connection with this section. Mr. Emmons says,[50] "The absence of nonconformity in the successive strata deposited, and their great uniformity throughout the area studied, show that no violent dynamic movement took place before the great disturbance at the close of the cretaceous, which extended throughout the whole of the Rocky Mountain System, and was doubtless the main factor in producing its present elevation." Again, on p. 479, in referring to the age of the Leadville deposits, he says, "Since they have partaken of the dynamic movements to which these rocks were subjected and were folded and faulted with them, they must have been formed earlier than those dynamic movements which, as the geological considerations already presented show, occurred not later than the close of the cretaceous period." The faults shown in Fig. 25 certainly came into existence either at the time of the great uplift above referred to, or later, but the ore was not formed until *after* the faults, and not as Mr. Emmons says, *before* them. The folding of the deposits affords no clue to their age. Being replacements, the

[49]Geol. Atlas of U.S.A. Ten Mile District, Special Folio, Colorado.

[50]U.S. Geol. Sur., Geol. and Min. Industry of Leadville, Colorado, 1896, p. 31.

deposits would of necessity follow the folds of the beds replaced, however much younger they might be, and the occurrence of pieces of ore in the crushed material along a fault-plane may be a result of one or more of the later differential movements, and not of the primary fracture and dislocation.

Stems of crinoids and shells of molluscs are sometimes found in ore-deposits, converted into ore similar to that in which they are embedded, as in the zinc carbonate of the Magdalena Mountains of New Mexico and the hematite deposits of Cleator Moor and Furness. In all these districts the country rock is limestone, and there can be no doubt the metallic minerals replaced that rock in forming the deposits, as well as the calcite in the organic remains.

As partly related to this portion of our subject, but more for the purpose of showing the flux and reflux of mineral deposition, the epimorphs of quartz on fluorite may be mentioned. In some cases the latter mineral has since been removed, a mere cast of its crystalline form being all that is left to vouch for its former existence. Similar cavities are met with in quartz veins where pyrite has been decomposed.

Mineral Association.—As already mentioned, certain minerals are frequently found together in ore-deposits. Why is this? Why should galena, blende and pyrite so often occur together, or chalcopyrite, pyrite, pyrrhotite and stibnite; or cassiterite, wolframite and arsenopyrite, gold and pyrite, silver and lead, or iron and manganese. It is very suggestive that in the case of some of these associations the specific gravities of the several minerals differ but very little. For example:—

In Tin Deposits	Specific Gravity
Cassiterite	6.8 to 7.0
Wolframite	7.1 to 7.5
In Copper Deposits	
Chalcopyrite	4.1 to 4.3
Pyrite	4.5 to 4.6
Pyrrhotite	4.9 to 5.2
Stibnite	4.6 to 4.7

In Iron Deposits	Specific Gravity
Iron Oxides	4.9 to 5.3
Manganese	4.7 to 5.0

Another fact of importance is that, the abundance of the metallic minerals in the accessible part of the earth's crust is to a large extent inversely proportional to their specific gravities. For example: iron, with a specific gravity of 7.8, is more abundant than copper having a specific gravity of 8.9; silver, with a specific gravity of 10.5, is less abundant than copper, and all are much more abundant than either tungsten, gold or platinum, with specific gravities of 19.1, 19.3, and 21.5 respectively. Zinc has a lower specific gravity than iron, but is not nearly so abundant. Its solubility when altered to the sulphate is certainly responsible for the removal of much zinc from the zone of weathering, but the manner in which it becomes locked up with lead at high temperatures, as explained later, is most probably the principal reason for its reduced quantity in orebodies as compared with iron. The deeper a metal or mineral sank in the cooling magma, the less likely would it be to reach the surface, or near thereto, again, which in all probability explains the rarity of gold, platinum, and similar heavy metals, as compared with iron, copper, lead, etc.

In lead-bearing deposits we find an association in which the specific gravities of the different metals vary much more than those given above.

	Specific Gravity
Galena	7.2 to 7.6
Blende	3.9 to 4.2
Pyrite	4.9 to 5.2

There is, however, a curious fact in connection with zinc and lead which probably explains the association of these minerals in ore-deposits. Zinc[51] takes up 1.7% of lead at its

[51]Hand-book of Metallurgy, C. Schnabel, 1907.

point (415°C.), 5.6% at 650°C. and 25.5% at 900°C. The average specific gravity of a mixture of 25.5% lead and 74.5% zinc is 7.9. The specific gravity of iron is 7.8. Both zinc and lead have such a low melting point that it is probable they would be entangled together in the cooling magma, and in that way be prevented from taking up the different positions due to their respective specific gravities.

Gold, silver, and pyrite are in frequent association, although their specific gravities differ greatly.

	Specific Gravity
Pyrite	4.9 to 5.2
Silver	10.51
Gold	19.3

We know that gold and silver form alloys in all proportions, so that they would probably sink in cooling to the same horizon. Their association with pyrite will be dealt with later.

Chemical Considerations.—All underground waters contain mineral matter in solution, but it is not of the kind to produce ore-deposits, which clearly have been formed at certain times only, when the waters circulating through the rocks contained the necessary metals in sufficient quantities.

Precipitation may be produced by either evaporation, or the cooling of saturated solutions, or by the chemical action of some liquid or solid on mineral-bearing solutions. Of these processes we have frequent illustrations in our laboratories. If crystals of galena and blende were formed in either the first or second way, they must have existed as sulphides in the solutions from which they were deposited, and so with other sulphide crystals. Doelter has shewn that pyrite, arsenopyrite, chalcopyrite and bournonite are all soluble in sodium sulphide, so that crystals of these minerals might result from the cooling of hot solutions of double sulphides, and amorphous sulphides might be precipitated otherwise, but either or both of these processes would account for but a part of ore-deposits—the part formed in cavernous spaces.

The quantity of solid matter that can be dissolved in an acid or alkaline solution increases in most cases with the heat of the solution up to a certain point. The quantity of gaseous matter that can be dissolved in water *decreases* as the temperature rises and at the boiling point is nil. The latter fact has an important bearing on the depth at which mineral-bearing solutions may be formed in the rocks. As already stated, it is improbable that, in the faulted areas where metallic mineral deposits are found, water exists at a greater depth than 12,000 feet, as, at that depth, and probably much less in some cases, it will be converted into steam by the heat of the rocks. Therefore the free gases which are essential to form the carbonates, chlorides and sulphates of the metallic minerals could not exist. They might, however, reach such depths in combination with bases.

We may here consider some of the chemical reactions that may have taken place in the production of mineral deposits. The silica that occurs so abundantly in many mineral deposits most probably came from the decomposition of the silicates which form the country rock of such deposits, according to the following or similar equations:—

$$K_2SiO_3 + 2HCl = SiO_2 + 2KCl + H_2O$$

$$Al_2O_3, SiO_3 + 6\,HCl = SiO_2 + Al_2Cl_6 + 3\,H_2O$$

and so for other silicates.

The earths and alkalies, or part of them, having been removed in solution, the silica, or part of it, would be left behind, only partly filling the space previously occupied by the silicates, and, as decomposition would take place most rapidly along lines of jointing, it is probable that the residual silica would be left in a more or less reticulated form.

One of the first metallic minerals to be formed in many deposits is siderite, which may result from a solution of iron, either coming into contact with a calcareous rock, or being passed into a solution of calcium carbonate, as under:—

(1) $FeCl_2 + CaCO_3 = FeCO_3 + CaCl_2$

(2) $FeSC_4 + CaCO_3 = FeCO_3 + CaSO_4$.

A good illustration of the early occurrence of siderite in deposits is found in the Bunker Hill and Sullivan Mines, Idaho. Mr. F. L. Ransome[52] says, "The quartzite was first replaced by siderite, which was in turn replaced by galena. All stages may be seen, from siderite that is traversed by little reticulating veinlets of galena to complete replacement by the lead sulphide." Mr. Ransome does not suggest how the quartzite was replaced. Probably the first stage was the decomposition of the sericitic quartzite and the deposition of carbonate of lime. Then the replacement by siderite would proceed as above.

If the spaces left in a vein, after the removal of the earths and alkalies, be occupied by a solution of ferrous sulphate[53] and auric tri-chloride rise into it from below along a fault-plane or through the joints and cells of an igneous rock, or through the fractured rocks adjoining the fault-planes and the intrusives, a deposit of gold would take place according to the following equation:—

$$6\ FeSO_4 + 2\ AuCl_3 = 2\ Au + 2\ Fe_2\ (SO_4)_3 + Fe_2\ Cl_6.$$

Silver alloying with gold, chloride of silver might be formed at the same time; it is soluble in sodium chloride, which is abundant in mineral waters, so that the silver might be precipitated along with the gold.

Ferrous sulphate could not exist in a calcareous rock, nor could it exist in large quantities in a rock containing much calcareous matter, as the reaction indicated in (2) would take place. The silicate rocks in which gold mostly occurs contain very little lime. Even the gold ledge of Mercur, Utah, in which the gold occurs in association with an igneous sheet and is both underlain and overlain by limestone, cannot be looked upon as an exception, for the ledge is highly siliceous and contains little lime, as shown by the following particulars of the gangue-minerals in the sulphide ore:—

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[52] *Mining and Scientific Press*, July 22, 1905.
[53] $FeS_2 + 7, O + H_2O = FeSO_4 + H_2SO_4$.

	%
SiO_2	66.42
Al_2O_3	14.85
Fe_2O_3 and FeO	.31
FeS_2	6.60
CaO	.35
MgO	.83
K_2O	2.73
Na_2O	.13

Even the little lime there is probably occurs as a silicate, which would not be acted on by the ferrous sulphate.

Potash in granite occurs as silicate which can be decomposed by water at a high temperature. If we assume the existence of KOH in the joints and cavities of granite into which tin chloride is introduced from below we obtain the following equation:—

$$SnCl_4 + KOH = SnO_2,\ 2\ H_2O + 2\ KCl.$$

In other words we have a deposit of tin oxide. The occurrence of cassiterite as a pseudomorph after orthoclase, mentioned by C. le Neve Foster,[54] is very suggestive, and similar occurrences are seen in other tin mining districts.

To produce chalcopyrite is a much more complex matter, because it is a combination of two metallic minerals which belong to different chemical groups. The precipitation of the copper was probably due to the reducing action of a copper solution on ferrous bi-sulphide, by which the iron was altered to Fe_2S_3, and the copper was precipitated as Cu_2S. The pyrite, perhaps, replaced siderite.

A frequent associate of chalcopyrite is pyrrhotite, which may have been produced somewhat similarly to pyrite, but probably at a higher temperature.

If, through a solution of sulphuretted hydrogen occupying the cavities of a vein or other form of deposit, lead chloride were passed, lead-sulphide (galena) would be precipitated thus:—

$$PbCl_2 + H_2S = PbS + 2\ HCl.$$

[54]Remarks on some Tin Bodies in St. Agnes District. Trans. Geol. Soc. of Cornwall, 1877.

If into a solution of ammonium sulphide a neutral or alkaline solution of zinc were passed, zinc sulphide (blende) would be precipitated.

$$ZnSO_4 + (NH_4)_2S = ZnS + (NH_4)_2SO_4.$$

Iron and manganese being thrown down by the same precipitant as zinc, we have a probable explanation of the occurrence of these minerals in blende.

These suggestions are sufficient to illustrate the argument I am seeking to enforce. All the reagents employed above are found, as already stated, in volcanic emanations, and exist abundantly in underground waters. At all times they are probably produced by the decomposition of minerals included in the rocks, and then dissolved in the waters circulating underground by gravity. By the oxidation of pyrite—a rock-forming mineral—we get sulphuric acid. Common salt occurs abundantly in underground waters. By the action of sulphuric acid on that salt, hydrochloric acid is produced.

$$2\ NaCl + H_2SO_4 = Na_2SO_4 + 2\ HCl.$$

With these two acids either sulphates or chlorides can be formed.

The manner in which it is suggested the metallic minerals were brought into contact with the precipitants will be described later.

Whether the conditions existing at the time the deposits were formed were agreeable to the combinations and decompositions that have been suggested above we can only surmise, just as we can only suggest why a deposit followed a particular bed, or a particular part of that bed, in preference to other beds or other parts. If we know exactly the conditions prevailing at the time we should be able to speak with much greater certainty.

Age of Deposits.—It is not possible to ascertain, even approximately, the age of many deposits. Of most of them it can only be said that they are younger than the rocks in which they occur, but how much younger it is often impossible to say. Such particulars, of a number of deposits, as are known are given below:—

Ores	Locality	Age of Country Rock	Age of Deposit
Gold	Tonopah	Tertiary	
"	Vulture mine, Arizona	Pre-Cambrian	Permian
"	Cripple Creek, Colorado	Tertiary	
"	Nagyag, Hungary	Tertiary	
"	Verespatak, Hungary	Cretaceous	
"	California	Jurassic and Cretaceous	Cretaceous or later.
"	Gympie, Queensland	Carboniferous	
Gold and Silver	Monte Christo, Washington	Tertiary	Late pliocene or early pleistocene.
" " "	Comstock, Nevada	Tertiary	
" " "	Mercur, Utah	Carboniferous	
Silver	Cerro de Potosi, Bolivia	Tertiary	
"	Cerro de Pasco, Peru	Cretaceous	
Tin	Devon and Cornwall	Devonian and carboniferous	Post-carboniferous.
Copper	Devon and Cornwall	Devonian and carboniferous	Post-carboniferous.
"	Boleo, California	Tertiary	
"	Clifton and Bisbee, Arizona	Silurian and carboniferous	Post-cretaceous.
"	Mannsfeldt, Germany	Permian	
" and gold	Rossland, British Columbia	Triassic and jurassic	Post-jurassic.
" and silver	Butte, Montana	Post cretaceous	Late eocene, probably.
Lead and Silver	Eureka, Nevada	Cambrian	Post-carboniferous.
" " "	Rico, Colorado	Carboniferous	Probably late tertiary.
" " "	Leadville, Colorado	Silurian and Carboniferous	Post-cretaceous.
" " "	Elkhorn, Montana	Late Cambrian	Late eocene.
" " "	Alston, Weardale, &c	Carboniferous	Post-carboniferous.
" " "	Pontgibaud, S. Central France	Gneiss and Mica-schist	Late miocene.
" " "	Slocan, British Columbia	Ordovician to carboniferous	Post-jurassic.
" " "	Rezbanya, S.E. Hungary	Triassic	
Lead and zinc	Bleyberg, Belgium	Carboniferous	
" " "	Raibl, Carinthia	Triassic	
Lead	Bleiberg, in the Eifel	Triassic	
Iron	Bilbao, Spain	Cretaceous	
"	Algeria	Jurassic	
"	Cumberland and Lancashire	Carboniferous	Close of carboniferous.
"	Scotland, Staffordshire, etc	Carboniferous	

There are many deposits in the older rocks which are not included in the above list, because there is nothing to show when they came into existence.

The silver-lead deposit at Eureka, Nevada, mentioned in the foregoing list occurs in Cambrian strata, but it was not formed until after Carboniferous times. The Palæozoic rocks of that district, from the Cambrian to the Carboniferous, are conformable throughout, and it was certainly not until after those rocks had been uplifted, tilted, and faulted that the ore was deposited. Mr. J. S. Curtis[55] thinks it was not deposited until some of the Tertiary rocks had been laid down. He bases that opinion on the fact that a rhyolite dyke of Tertiary age occurs in the main fault near which the ore is found, and from the relations of the ore and dyke he thinks the ore must be the younger. I am inclined to think, however, that it was quite possible for the dyke to be intruded after the ore had been formed, particularly as the latter occurs well within the foot-wall, except at two points where it is actually in contact with the rhyolite. Mr. Curtis says, "The fact that the rhyolite does not in any place contain enclosed fragments of ore, though it often contains country rock, goes to prove that the eruption occurred before the deposition of the ore." That limestone was much more likely to be included in the rhyolite than ore, is certainly to be expected when we remember that the area of it exposed to the abrasive action of the rhyolite is many times larger than that of the ore.

The silver-lead ore of Leadville is in Silurian and Carboniferous dolomitic limestone, but the ore was not deposited until after the Cretaceous period. Mr. Emmons thinks that the ore was deposited before the great uplift at the close of the Cretaceous, but it is clear from Fig. 25 that it was not formed until after the faulting, which, at the earliest, took place during the time of the subterranean activity which closed the Cretaceous period.

The hematite of Cumberland and North Lancashire was deposited during the period of violent disturbance at the close of the Carboniferous. Those rocks are conformable throughout, except at the upper part of the coal measures, and therefore, as the ore was not deposited until after the rocks in which it occurs

[55]Silver-Lead Deposits of Eureka, Nevada, U.S. Geol. Sur., 1884.

had been tilted and faulted, it must be younger than the bulk of the coal measures, and as pebbles and other fragments of hematite occur in the middle Permian breccia, the deposit of the ore from which the pebbles were derived must be early Permian or pre-Permian. The mineral veins of the Lake District, the tin and copper deposits of Devon and Cornwall, and the lead deposits of Alston Moor, Allendale and Weardale, are probably about the same age as the iron deposits of Cumberland and Lancashire, but the evidence is not sufficient to enable us to speak more definitely.

The iron ores of the Mesabi Range occur in Huronian rocks, but what the age of the ores is cannot be said. They are clearly younger than the rocks in which they lie, but older than the Cretaceous, because pieces of iron ore and of the rock in which the orebodies occur are included in the Cretaceous conglomerate which rests in patches on the ore-bearing formation. During the enormous lapse of time between the elevation of the iron-bearing rocks above sea level—in post-Keweenawan days—and their submergence prior to the deposision of the Cretaceous conglomerate, they must have suffered very greatly from denudation. Therefore, unless the orebodies were deposited but a short time prior to the Cretaceous period, they must have been formed at a great depth, which is exceedingly unlikely, and that depth would be greater the farther back the birth of the deposits is assumed.

In looking over the above list, one cannot fail to be struck by the fact that the whole of the deposits included in it are younger than the Carboniferous rocks—some of them very much younger. Even the Mesabi ores may be no older. A probable explanation of the comparatively recent origin of ores may be found in the fact that, although hypogene disturbances were frequent in the early ages of earth building, yet the great thickness of silicates, and other non-metallic minerals which formed on the upper part of the crust as it solidified, must have provided practically the whole volcanic ejectamenta for ages. These outbursts provided the material which afterwards, by denudation and deposition, gave birth to the sedimentary and

other aqueous rocks. The thickness of these laid down to the close of the Carboniferous period was from 35,000 to 67,000 feet more than was deposited in the interval between the Carboniferous and close of the Pliocene. When, over any given area, the non-metallic minerals forming the external part of the primative crust had been more or less reduced in thickness, the lighter metallic minerals—such as iron—would have a better chance of reaching the water-bearing zone, the heavier coming later.

The frequent occurrence of ore-deposits in pre-Carboniferous rocks has no bearing on their age. Being older than Carboniferous rocks they were more likely to be intersected by faults and otherwise broken up than younger rocks, even by comparatively recent plutonic disturbances, and therefore more likely to be on the courses of ascending, heated, metal-bearing currents when they began to flow.

In a paper on Metallogenetic Epochs[56] W. Lindgren considers one of the periods of ore-deposition was pre-Cambrian, but there is nothing more to go upon than the fact that the deposits are in rocks of that age. It has never been conclusively shown, so far as I know, that they are syngenetic; they are assumed to be, like the black band and clay band ironstones of our carboniferous rocks.

Sources of Ore.—The trend of recent thought on this branch of the subject is either to accept the lateral secretion suggestion of F. Sandberger, which assumes that the metals contained in the ores were derived by leaching from rocks more or less adjacent to the locus of the orebodies, or they are assumed to have come up as solutions or vapours from hotter regions below. One form of the latter idea supposes that the mineral-bearing solutions exuded from cooling magmas[57] and is employed to explain the origin of contact-deposits between igneous and aqueous rocks. One difficulty in the way of accepting that view is that of accounting for the localization of deposits on very limited areas of an extensive contact. Another is that many contact-deposits occur where there are not any igneous rocks, as, for example,

[56]Quarterly Bulletin, Canadian Mining Institute, July, 1909.

[57]J. F. Kemp on the Rôle of the Igneous Rocks in the Formation of Veins, Trans. Amer. Inst. Min. Engrs.

the hematite deposits of Cumberland, which frequently occur along contacts of limestone and shale and limestone and sandstone. A further difficulty is in accounting for the association of metals. If it be supposed that the metallic minerals of orebodies adjoining igneous rocks came from those rocks, it is remarkable that they should have given off practically all they held. It seems to me much more likely that the pores and fractures of contraction in the igneous rocks, and disruption in the adjacent rocks, formed channels through which the metallic solutions rose from below to their present resting places.

By separating some of the minerals forming part of silicate rocks and subjecting them to chemical analysis, Sandberger[58] found small quantities of a number of metallic minerals. In olivine he found iron, nickel, copper and cobalt, the last in very small quantities. In augite he found copper, cobalt and iron, sometimes, also nickel, tin, lead and zinc. Antimony and arsenic were found in the diabases of St. Andreasberg in the Harz. Hornblende was in some cases found to contain copper, arsenic and cobalt; in others antimony and tin were also found, occasionally zinc and bismuth. Micas have been found to contain a number of metals. Lithia micas are stanniferous and usually also contain arsenic, copper, bismuth, and sometimes uranium. Black micas of the old gneiss of the Erzgeberge contain arsenic, lead, zinc, and a little copper. Black mica from the Spessart contains copper, cobalt, nickel, and bismuth. In the dark mica of the Schemnitz propylite, arsenic, lead and zinc are found.

Analyses of Cornish granite do not show any lithia. Moreover, the association of metals in the various silicates tested by Sandberger is not the same as we find in mineral deposits. Further, many ore-deposits are found in limestones far removed from rocks containing such minerals as were tested by Sandberger.

Small amounts of metallic minerals have been found in both igneous and aqueous rocks, but it has never been shown, so far as I am aware, that the quantity increases with the distance from an orebody, as it would if the latter were due to leaching of the adjacent rocks. In my experience the reverse is the case.

[58]Untersuchungen über Erzgange. Part I, p. 23.

In assuming that the metallic minerals of orebodies have been leached from the adjacent rocks, we are confronted by a serious difficulty in underground circulation. The minerals from which it is assumed the metals were derived are more or less disseminated throughout the particular rocks looked upon as the source of those minerals, but the circulation of underground water, except in the case of porous sandstones, can only take place along lines of jointing or fractures, or by cavernous and vesicular spaces. Assuming that there is interstitial moisture in a block of undivided rock, what is there to induce that moisture to move towards any of the joints that surround the block ? and unless there is a movement outward, leaching could only take place in the rock immediately adjacent to the joints. There being more hydraulic head on the water in the joints, fractures or other spaces than on the interstitial water in the centre of the block, the pressure would be toward the centre of an undivided block rather than from it.

Becker[59] is of opinion that the metallic minerals in the ore of the Comstock mines in Nevada, were introduced into the orebody by the segregation of minute quantities of those minerals dissolved from the adjacent eruptive rocks. He bases his opinion on the assay results of 14 random samples of diabase taken in the neighbourhood of the mine. This rock forms nearly the whole of the hanging-wall for a length of about 12,000 feet. Of the samples, 4 are said to have been fresh. They had an average value, in silver, of 14½ cents per ton. Seven of the samples were decomposed, some highly so. These gave an average value of 12-27 cents per ton. Nine of the samples were taken in the Sutro tunnel; 1 in the 1,600 feet level of the Overman mine; 1 in the 2,500 feet level of the C. & C. mine; 1 in the 1,900 feet level of the Chollar mine, and 1 from the Julia dump. On p. 224 Mr. Becker says, "By comparison of the different assays it appears that decomposed diabase carries somewhat less than half as much silver as the fresh rock." I do not make it so, as will be seen from the average figures just given. Mr. Becker seems to think that the smaller quantity of

[59]Geology of Comstock Lode; by G. F. Becker, 1882, p. 224

silver in the decomposed rock favours the idea that silver has gone from that rock into the ore-deposit. But, before a fair comparison as to the relative value of the silver in the fresh and decomposed rock can be made, it is necessary to have an equal number of samples of each kind of rock. The highest silver in the fresh rock was 22 cents per ton, the lowest 5 cents. The highest in the decomposed rock was 18 cents, the lowest 10 cents. It will readily be seen that the addition of three more fresh samples might have altered the relative value entirely. Further, if reliance is to be placed on the idea that the country rock has been leached of some of its silver, the samples should have been taken in such a way as to show the diminution of the silver from the fresh rock, through the partly decomposed rock to the most highly decomposed; for, other things being equal, I think it is perfectly correct to say that the amount of leaching would be inversely as the distance from the orebody. But there is another consideration: the liquids circulating in the passages of the vein-space would be much more likely to force their way into the country rock, than that the interstitial liquids in the latter should bleed towards the vein.

Mr. Emmons[60] holds a similar opinion with regard to the silver-lead deposits of Leadville, and the Rosita and Silver Cliff Districts of Colorado.[61] He looks upon the white and other porphyries overlying and intersecting the ore-bearing limestones of Leadville as the source of the metallic mineral deposits of that district. The assays of 46 samples tested for gold and silver yielded the following results:—

Samples Tested	Gold Contents	Samples Tested	Silver Contents
35	None	12	None
5	Doubtful	3	Trace
4	Trace	31	Weighable quantities
2	Weighable quantities	—	
—		46	containing .139-oz. per ton.
46	containing .0035-oz. per ton.		

[60]Geology and Mining Industry of Leadville, p. 379.

[61]The Mines of Custer County, Colorado; U.S. Geol. Sur., 17th Annual Report, Part II.

The ratio of gold to silver in these assays is 1 to 39.7. In the Adelaide mine it is 1 to 127.

Here, too, the samples were taken at random, and without any attempt to show whether there is a more or less gradual diminution of silver and gold in the rocks as the orebodies are approached.

In both these enquiries and in all others having the same end in view the results sought do not meet all the questions to be answered. To take the Leadville deposits as an example: It is not sufficient in that case to show where the gold and silver came from. It is equally important to point out the source of the lead, zinc and iron, etc. These metals occur in much larger quantities than the gold and silver, and even if the whole of them had been abstracted from the decomposed rocks near the orebodies, their presence would have been quite evident in the far off, fresh, unleached rocks, and there would be some still left in the partly leached porphyry.

In seeking the source of the minerals in the silver-lead deposits of Custer County, Mr. Emmons had assays made for silver of 9 samples of eruptive rocks from the neighborhood of the mines. Four of these samples did not contain any silver. The other 5 contained an average of .088 oz. per ton, ranging from .005 to .402 oz. per ton. They do not, however, prove the point which Mr. Emmons sought to establish. The samples were taken at random, and not with the view of showing that the country rock adjacent to the deposits had been leached of metallic elements similar to those in the orebodies.

In his investigation of the Eureka silver-lead deposits, Mr. Curtis[62] took a number of samples of the limestone, in which the orebodies occur, along two different drifts leading up to the ore in the 600 feet level of the Richmond Mine. Forty-three samples—25 feet apart—were taken from one drift (1) and 18 samples—also 25 feet apart—from the other (2). The first sample of (1), taken from the limestone 1,000 feet from the orebody to which the drift led, contained silver of the value of 9 cents per ton. The last sample taken close up to the orebody,

[62]Silver-lead Deposits of Eureka, Nevada; U.S. Geol. Sur.

contained 30 cents in silver per ton. Midway between these two the limestone gave a value in silver of 16 cents per ton. In set (2) the first sample, 650 feet from the orebody, gave a value of 6 cents per ton, the last, at the orebody—32 cents per ton. At 325 feet from the first sample the value was 11 cents.

The orebodies at Eureka contained a large quantity of iron oxide, almost one-half of it being of that mineral, the remainder being lead, arsenic, sulphur, zinc, silver, etc., and Mr. Curtis says, p. 81: "The first four of these substances do not seem to occur in the least metamorphosed limestone, and only appear in the more altered limestone in small bunches and seams in the neighbourhood of the orebodies." The silver found in the two sets of samples showed, according to Mr. Curtis: "That the country rock near the orebodies is richer in silver than that at some distance from them, that the least changed and metamorphosed limestone is the poorest, and that the most crushed and broken limestone, and that which is somewhat stained with ferric oxide, is usually the richest." He then says: "From the foregoing facts it will be seen that it is scarcely possible that the orebodies could have been formed by segregation from the surrounding limestone. The assays prove, moreover, that the silver in the rock was in all probability an impregnation accompanying the deposition of the orebodies, and was not an original constituent of the limestone."

Mr. W. Lindgren,[63] writing on this subject with reference to the gold-quartz veins of Nevada City and Grass Valley Districts of California, says: "A series of assays was carefully made by Mr. C. Whitehead, the assayer of the Mint, with a view of finding minute traces of gold and silver." After giving a number of the results so obtained, Mr. Lindgren concludes: "Though fragmentary and unsatisfactory, these results seem to indicate that traces of gold are not common in the rocks of the district. They further seem to indicate that wherever anything is found, it is silver and not gold which predominates, while the reverse is true of the veins. It is not believed that the bulk of the metals of the veins is derived from the rocks immediately adjoining the veins." In this connection it may be pointed out that at the

[63]U.S. Geol. Sur. 17th Annual Report, Part II.

Tyee mine on Vancouver Island, the orebody contains about 37% of barite, although there is not any in the adjoining rocks. Barite is, perhaps, the only non-metallic mineral that was not deposited by meteoric waters. The granodiorite of Grass Valley and Nevada City contains an appreciable amount of barium, but there is not any barite in the veins.

The suggestion that the immediate source of the metallic minerals in orebodies was the adjacent rocks affords no explanation of the facts that in some districts, as in Cornwall, for example, one set of veins, having a more or less east and west direction, contain tin and copper, whilst another set, bearing northerly and southerly, produce lead and iron. If all these metals were at one time in the surrounding rocks, we would surely have found them in all the veins. By assuming that they came from different subjacent zones, at different times, and depending upon the depth from which the local plutonic activity caused them to rise, we can understand why certain metallic contents of veins are confined to those having particular directions. The veins having different bearings were formed at different times. The sequence of energetic impulses which gave rise to them probably arose during one period of activity in the tin-copper zone, while in another period they were confined to the iron-lead zone.

The Forming of Orebodies.—Wherever it has been possible to determine the age of deposits with any approach to accuracy, it appears there was great plutonic activity preceding their birth. It also seems certain that all deposits of which the age is known are younger than the latest carboniferous rocks, and that, prior to that period, enormous masses of igneous matter had been forced up to, or thrown out upon, the earth's surface and converted by meteoric and other agencies into the various stratified rocks now forming such a large part of the earth's external crust. These early upheavals and out-pourings consisted at first, most probably, of acidic rocks followed later by more basic material. Although the plutonic rocks were not poured out and scattered over the surface like those of volcanic origin, they were pushed up time after time, and some of them eventually, like the latter, became subjected to severe denudation from the sea, rain, rivers,

frost, and chemical action. The immense thickness of stratified rocks formed out of the destruction of the uplifted and ejected materials prior to the close of the carboniferous period means the removal of that amount of lighter acidic matter from below, and the sinking or settlement of the relatively thin solidified crust, with its added burden of stratified rocks and an increasing weight of water, on to the heavier igneous matter beneath.

During the periods of plutonic activity which at no great length of time preceded the birth of ore-deposits, the throw of existing faults might be increased, new faults formed and passages made through the stratified rocks by molten matter forced partly or wholly to the surface. Some or all of such intersections of the strata would form exits for the various metals or metallic minerals existing below to the rocks above. Those rocks might be stratified, like the Killas and limestone of Cornwall and Leadville respectively, or, they might be massive, like the granites of Butte and Cornwall. Many, if not all, of the metallic minerals in all probability passed up as gases and became dissolved in the waters existing in the rocks above, at no great distance from the surface, as already indicated. If those rocks were silicates, and cavernous spaces had been formed in them which contained the necessary reagents, such as might be conveyed there in the waters circulating by gravity, the metallic minerals would be deposited in those spaces; or, the metal-bearing solutions might attack the calcite and (or) dolomite veinlets formed as already suggested, and effect replacements. If the rocks were entirely calcareous, or partly so, as at Alston, Weardale, etc., they would, in part, be replaced metasomatically by the metals in solution. The manner in which dolomite has replaced silicate rocks and been itself afterwards replaced by a metallic mineral is very clearly shown in my paper on the "Mineral Veins of the Lake District"[64] from which Figs. 26 and 27 are taken.

On the depth at which the volcanic action originated, would depend the kind of metal that would find its way to the zone of deposition. The metals or metallic minerals having

[64]Trans. Manchester Geol. Soc., 1884.

nearly the same specific gravity might in this way be expected to form parts of the same deposits, just as we find together chalcopyrite, pyrite, and pyrrhotite, the first consisting mainly of copper and iron, the last two of iron and sulphur. In all probability these minerals (and all other metallic minerals) rose to the water-bearing zone in a gaseous form and were dissolved in one or other of the acid solutions permeating the rocks. In the particular case just mentioned, the copper probably existed in the depths as an oxide, the specific gravity of which is about 5.9. The iron would, in all probability, also exist as oxide, and have a specific gravity of about 5.7, so that when the conditions were such as to vaporize one, the other would probably undergo a similar change, the melting points being similar, and the two metals would be in solution at the same time.

Antimony, arsenic, and bismuth, often associated with copper ores, probably occurred in the molten magma as trioxides. Bismite (BiO_3) has a lower specific gravity than senarmontite (SbO_3), but higher than arsenolite (AsO_3). Bismite and arsenolite have a lower melting-point than senarmontite, and would therefore cool out after that mineral and consequently might sink to a greater depth than that due to their gravity. Their fall might be arrested in the senarmontite zone, which was probably that of copper oxide.

Although galena and blende are, perhaps, invariably associated, they were not formed at the same time. For the reason already given, they most probably occurred together in the deep, but, belonging to two different chemical groups, they could not be precipitated by the same reagent unless in a neutral or alkaline solution, although as gases they might rise simultaneously and become dissolved in the same solution. They may have existed as oxides before being volatilized; the zinc might be formed into a sulphate and the lead into a chloride, lead sulphate being insoluble in water. The zinc could be precipitated by ammonium sulphide from a neutral or alkaline solution, and the lead by hydrogen sulphide from an acid solution. The succession of depositions may have arisen from the succession of precipitants. The association of pyrite with galena and blende

probably arose from these latter materials having been entrapped in the cooling magma in the same zone as iron. The specific gravities of the oxides of the three associated metals are:— Zinc oxide 5.6, lead oxide 8, iron oxide 5.7; but, from the fact already referred to that zinc at 900° C. takes up more than 25% of lead, the mean specific gravity of the two will be about 6.

Gold and silver, although of very different specific gravities, are almost invariably found together in mineral deposits, but in no definite proportions. These facts probably arise from the further fact that the two metals form alloys in almost all proportions. They would therefore be found together in the cooling magma, and, when the heat was sufficient to vaporize them, their melting points being very little different, they might rise and be dissolved together as chlorides in the solutions circulating in the water zone.

The suggestions herein made that vapours of the metals or of metallic oxides, became dissolved in the acidulated waters permeating what may properly be called the water-bearing zone of the earth's crust, affords a reasonable explanation of the fact that deposits do not extend downwards to very great depths. They would be, in all cases, limited in depth to the water-bearing zone, and, in deposits formed in cavernous spaces, they would probably be limited to the zone of circulation by gravity, the depth of which may vary at different times according to changes in the altitude, in the surface configuration, and in the geological structure.

Mr. J. E. Spurr[65] has pointed out that in the ore-deposits of Monte Christo, Washington, which occur in igneous rocks of Tertiary age, the lower limit of the galena was found at depths of from 50 to 250 feet from the surface, being to a considerable extent parallel thereto, as shown in Fig. 28.

The other base metal minerals in that deposit are blende, chalcopyrite, pyrite, and arsenopyrite. The lower limit of the blende is below that of the galena, and that of the chalcopyrite deeper than the blende. The arsenopyrite and pyrite occur in

[65]U.S. Geol. Sur. 22nd Annual Report.

the Mystery and Pride mines to a depth of about 500 feet, being lower than the chalcopyrite. Like galena, the other minerals extend upwards to the surface.

The rough parallelism of the lower limit of the galena to the surface and the increased extension downwards of the different minerals as stated, are looked upon by Mr. Spurr as evidence that they were deposited by *descending* waters. Mr. W. H. Weed[66] of the U.S. Geological Survey, who was, perhaps, the first to point out this feature in the distribution of these minerals, considers it, like Mr. Spurr, to have arisen from change of pressure, but he supposes the minerals to have been deposited from *rising* metallic solutions. I cannot think that variation of pressure and temperature would produce the effects observed. The whole of the minerals are found in the veins side by side from the surface downwards for a certain depth; galena cuts out first, then blende, later chalcopyrite, and finally pyrite and arsenopyrite. Had their precipitation been due to changes of temperature, it seems to me we should have found a distribution in which the galena occupied a zone above the blende, the latter a zone above the chalcopyrite, and the pyrite and arsenopyrite occurring in a zone at the bottom.

I think there is another explanation. The mineral deposits at Monte Christo are comparatively recent, so that the surface, although extensively denuded, may not differ much in its present sectional form, vertically, from that which it had at the time the ore-bodies were deposited. The ground-water probably extended downwards in a zone more or less parallel to the surface, so that the rising vapours, becoming dissolved in the ground-water, would form a deposit, having its lower limit more or less parallel to the surface then existing, and, for the reason given, to the present surface. The order of formation was probably arsenopyrite, pyrite, chalcopyrite, blende, and galena. The ores are most abundant near the surface, and diminish downwards. Some of them are products of metasomatic replacement, the others were most probably deposited partly in cavities of the preceding minerals and partly by replacement. The metallic

[66]Trans. Amer. Inst. Min. Engrs., 1903.

minerals in the latter case probably followed calcite or dolomite. The rep'acements by arsenopyrite and pyrite would give rise to a number of cavities, owing to their smaller volume. As the quantity of mineral increased upwards—owing to the increasing quantity of calcite in the rocks and the increasing strength of the mineral solutions—so the number of cavities would increase. Some of these might be filled by chalcopyrite, but in the upper part of the veins there might be still unfilled cavities, some of which might be filled by blende. Finally, galena would fill the remaining cavities in the uppermost parts of the veins. The deposition of the different minerals must have taken place at different times, no matter whether the precipitation was a physical or chemical effect, otherwise there would have been a mixture of metals quite unlike anything we find.

The purpose of the preceding illustrations is to enforce the idea that metals, or compounds thereof, which occur in the same 'mixed' ore-deposits, came from the same subterranean zone. Whether they came up in the particular form suggested, we do not know, and may never know, but it would be something gained if we could feel sure they came up as vapours and were dissolved in the ground-water. We may never know the exact course of terrestrial evolution, but the establishment of a number of even isolated points on the way is vastly more satisfying than a helpless confession of incomprehensibility.

Senarmont[67] has shown that quartz, siderite, smithsonite, rhodochrosite, barite, stibnite, arsenopyrite, pyrargyrite, etc., may be produced in a crystalline form in water heated from 130° to 300° C.

Galena and magnetite have been produced by sublimation in furnaces.

Daubrée,[68] by the help of chlorides and fluorine, etc., produced, by sublimation, tin oxide and oxide of titanium. Durocher[69] obtained similar results by passing metallic vapours

[67]Annales de Chimie et de Physique. Vol. xxviii, p. 693, and Vol. xxxii (1851).

[68]Comp. Rend. Vol. xxix, 1849, p. 227.

[69]Comp. Rend. Vol. xxxii, p. 823 (1851), and Vol. xlii, p. 850 (1856).

through heated glass tubes, forming in that way blende, pyrite, galena, etc.

The depth to which orebodies descend is very variable, the greater depths occurring in veins. The workings of the Morro Velho vein in Brazil have reached a depth of about 5,000 feet vertically. A similar depth has been worked at Bendigo in Australia. In both cases the vein goes still deeper.

In some cases the grade of the ore diminishes downwards; occasionally this arises from a widening of the deposit and a spreading out of the metallic minerals, rather than from a reduction in their quantity.

In a paper on the "Differences of Depth in the Original Position of Epigenetic Deposits," Professor Vogt[70] says, "In many epigenetic ore-deposits of Archaean-Algonkian or Palaeozoic age mining has been carried to depths of 2,500, 3,300 to 4,100, and 4,100 to 5,000 feet. Taking the depth roughly as 3,300 feet, and assuming that in some districts the present surface has been denuded 10,000, and in others 13,000 feet, below the surface at the time of the ore-formation, we may say that mining has reached a depth of 10,000 feet to 13,000, or 13,000 to 16,000 feet below the original surface. We conclude, then, that under favourable circumstances the ore-veins may continue at least to a depth below the original surface of 10,000, 13,000, 16,000 feet or more." The depth to which veins descend below the level of the surface existing at the time they were formed, depends upon the age of the veins, not of the rocks in which they occur. Without knowing the former, any figures as to denudation are merely unsupported guesses.

In an article on "the Genesis of Ores in the Light of Modern Theory," Mr. H. V. Winchell[71] says, "We find our best ore shoots on the sunny side of the mountains, while the veins on the northern, shaded sides where the snow lies till midsummer and the rocks are cold, produce no such rich ore." The Slocan District of British Columbia does not support this statement. There the snow lies even later than midsummer on some of the richest

[70] Trans. Amer. Inst. Min. Engrs., February, 1901.
[71] *Engineering and Mining Journal*, December 7th, 1909.

deposits in the country. The sunny side of mountains offers greater facilities to the prospector and more congenial occupation than the cold shaded and snowclad side, just as the temperate regions are more attractive to the miner than the Arctic or sub-Arctic regions. Further, it must not be forgotten that climatic conditions are not permanent. In the far-away time when some of our orebodies were forming, both orological and meteoric features might be, and in all probability were, very different from what they are to-day. Not only original depositions, but even secondary enrichments, may have taken place in circumstances quite unlike those we now know.

The foregoing remarks are not intended to apply to detrital ore-deposits, the origin of which is much more apparent. Although some writers have held that detrital gold was deposited from solutions because some gold has been so formed in detrital deposits—yet it seems much more in keeping with the facts to say that in the main it came from the destruction of older deposits.[72]

PART II

EXAMPLES OF DIFFERENT FORMS OF DEPOSITS

It is not intended to describe every kind of deposit, nor any of them in full detail, but only some of the deposits that have been largely worked and carefully studied, and such of their features as appear to have a bearing on the question of origin. Matters, such as secondary enrichment—relating to modifications of the original deposit—will not be dealt with except in a very general way.

Vein Deposits

The Gold Veins of California.—These are so numerous and occur throughout such an extensive area, that a selection only can be made. As the veins in the districts of Grass Valley and Nevada City have been very carefully studied by the U.S. Geological Survey[73] these notes will be confined to those areas.

[72]Auriferous Alluvium of the Fraser River, by J. D. Kendall.

[73]The Gold Quartz-Veins of Nevada City and Grass Valley Districts, California, by W. Lindgren, U.S. Geol. Sur., 17th Annual Report, Part II.

The veins are quartz-veins, and, like similar veins in other districts, are frequently spoken of as 'fissure-veins,' but the evidence is all against the idea of the ores having been deposited in fissures. In form they are like filled fissures, just as irregular deposits are like filled caverns, but there the resemblance ends.

The prevailing rocks of the districts are of igneous origin, of Jurassic and early Cretaceous age. There are a few sedimentary areas consisting of argillites, slates, sandstones, and schists, partly of Jurassic and partly Carboniferous age. The principal veins are in granodiorite, diabase, porphyrite and the calaveras formation. The granodiorite is the latest of the igneous rocks and is probably of early Cretaceous age. The chemical composition of some of the principal rocks in which the gold-bearing veins occur is given by Lindgren as under:—

	Granodiorite	Diabase	Argillite of Calaveras Formation
	%	%	%
SiO_2	68.85	51.01	73.63
TiO_2	.58	.98	.52
Al_2O_3	15.84	11.89	10.54
Fe_2O_3	1.91	1.57	1.87
FeO	2.75	6.08	
MnO	.07	Tr	CO_2 .62
CaO	4.76	10.36	2.47
SrO	Tr	Cu S Tr	Sr O Tr
BaO	.06	Cr_2O_3 .04	Ba O .12
MgO	2.07	8.87	1.84
K_2O	3.08	.15	1.89
Na_2O	3.29	4.17	1.81
Li_2O	Tr	....	Tr
H_2O below 100° C	.28	.24	.11
H_2O above 100° C	1.65	2.09	1.07
FeS_2	.04	1.73	Fe_7O_8 3.16
P_2O_5	.13	.17	.13
O of organic matter	....	....	.59

The directions of the veins are various, but may be included in two groups, one bearing more or less northerly and southerly, and dipping towards the east or west, the other group clustering, somewhat widely, about the east and west line and dipping either to the north or south. The former group is the older and is faulted by those bearing east and west. The veins are mostly on the lines of faults of small throw, so far as ascertainable, but the Merrifield and Ural veins are supposed to have a throw of over 1,000 feet. Many of the faults are overthrusts, and have low dips. For example, the Beckman vein has a dip of only 7½ degrees from horizontal, the Canada Hill vein only 20 degrees, Merrifield 29 degrees to 45 degrees, the Ural 35, and the North Star an average of about 20 degrees. Other veins, like the Eureka and Idaho have high dips—70 degrees to 73 degrees. The width of the quartz in some veins is only 6 inches or less. The Merrifield, Idaho and Omaha are 2 to 3 feet average, but in places the Merrifield has swelled out to 6 and 10 feet. Many of the veins in the Nevada City District are less than 2 feet.

The quartz carries native gold and metallic sulphides. The gold is generally fine, but coarse gold also occurs in many mines. The sulphides range from 2 to 3% of the ore—varying from ½ to 7%. 80 to 90% of the concentrate is pyrite, 3% chalcopyrite, 3% galena, and about 1.6% blende. There is also some arsenopyrite, pyrargyrite, stephanite, argentite, tetrahedrite, molybdenite and cinnabar.

The ratio of gold to silver varies from 7 to 4 or 5 in the Mountaineer mine; in the Champion from 1 to 7 or 10. The fineness of the gold ranges from 650 to 950; in the majority of veins from 800 to 860. Beside quartz, some calcite is found in all the veins. The richer ore occurs in shoots varying in length from a few feet to several thousand feet along the vein. The form of some of them is given in Fig. 29.

The ore does not end with the shoots, only that part of it which is known as 'pay-ore,' the remainder being of too low value or too thin to be worked.

The quartz is frequently sheeted, the planes being parallel to the walls of the vein. This structure is shown on the left

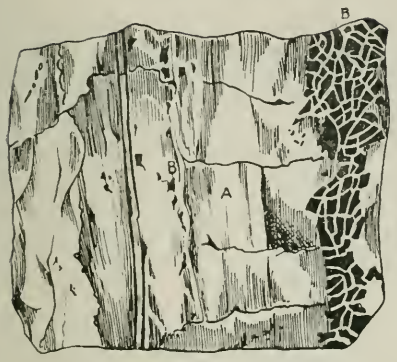
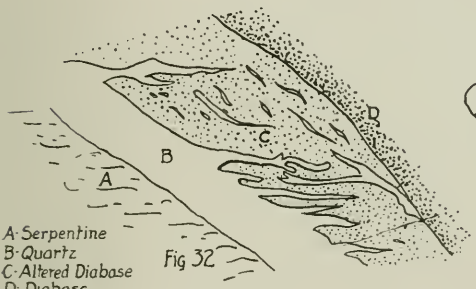
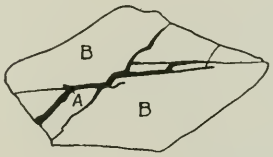


Fig. 30 A. Quartz B Pyrite

x 17 linear Fig 31 A-Gold B-Pyrite C-Quartz



A-Serpentine B-Quartz C-Altered Diabase D-Diabase Fig 32



A-Cassiterite B-Slate Fig 33

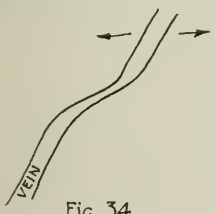


Fig 34

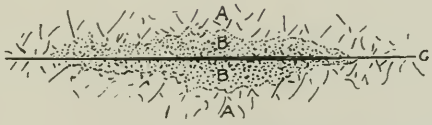


Fig 36 A Granite B Deposite of Cassiterite C. Quartz & Ferruginous Clay

side of Fig. 30. Fig. 31 shows how the gold occurs in pyrite, as seen under the microscope.

The manner in which the country rock has been broken up by the quartz in the veins has already been referred to, and partly illustrated in Fig. 18. Another section is given in Fig. 32.

Sections such as these are quite opposed to the idea of filled

fissures. The quartz-veinlets traversing C, in the sections given in Figs. 18 and 31, cannot be filled fractures. They are much more likely to be replacements. When seen under the microscope, they graduate into C. The larger bodies of quartz forming the principal part of the veins are either wholly replacements, or partly residual quartz in which the vacancies have been, to a greater or less extent, filled by quartz from other sources.

The very low angle at which many of these veins occur is conclusively against their being filled fissures.

Reference has already been made to Mr. Lindgren's opinion (p. 370) that the source of the metals in the veins is not the rocks immediately adjoining the veins, but, he thinks[73] "they were dissolved from the more deep-seated granodiorite. The thermal waters rising on the veins were doubtless surface waters from the higher parts of the range which penetrated to a considerable depth before reaching the surface again, but a few thousand meters would probably be the greatest depths attained by them." Mr. Lindgren does not explain why he thinks the deep-seated granodiorite more likely to contain the metals than that nearer the surface, but it is very probable that water which had circulated through a great depth of rock, as he suggests, would be less able to dissolve metallic minerals than water which had been less in contact with rocks, as its combining or dissolving power might have been more or less exhausted. Then there is the difficulty of vadose waters circulating at great depths.

The Copper and Silver Veins of Butte, Montana.[74]—The country rocks here are granite and aplite. The granite is part of the Boulder batholith covering an area of about 1,000 square miles and of post-Cretaceous age. Its composition is partly shown by the following table:—

	%
SiO_2	64.11
Al_2O_3	15.61
Fe_2O_3 and FeO	4.60

[73]Gold Quartz Veins of Nevada City and Grass Valley.

[74]This area has been carefully studied by the U.S. Geol. Sur., some of the results of which are herein utilized.

	%
Ca O	4.13
Mg O	2.15
K_2 O	4.12
Na_2 O	2.78

The aplite occurs frequently as veins in the granite, but also as a mass having an area of about 1½ square miles. The granite has also been invaded by one or more intrusions of rhyolite. Dykes of quartz porphyry occur in association with several of the large copper veins in the granite. The veins intersect the dykes and slightly displace them. The copper veins are found only in the granite. The silver veins occur in both the granite and the aplite. The copper veins always carry silver, but the copper in them gradually decreases towards the aplite. The silver veins in the aplite are generally strong and well-defined, but too low in silver and too high in zinc to be profitably worked. Some of the silver veins, at a depth approaching 1,000 feet, are copper-bearing. The upper part was probably once copper-bearing also, but has been leached.

The directions of the veins vary, but all lie within 45° of an east and west line. Some of them are vertical, others dip at angles about 10 to 25° from vertical. Many of them do not come up to the surface. In the crosscut-tunnel driven from the Alice shaft to the Blue Wing lode, at the 1,000 feet level, (5,300 feet above sea level) 8 mineral-bearing veins were cut, only 3 of which appear at the surface, and in a similar crosscut between the Anaconda and Bell shaft (5,000 feet a.s.) 20 such veins were crossed, but only 2 or 3 have been recognized at the surface. In places spurs branch from the main veins. At other places several smaller veins occur close to the main one, and the ground between them is more or less mineralized.

The oldest veins—such as the Anaconda, Parrot, Mountain View, West Colusa and Syndicate, are locally called "quartz-pyrite veins." They have a more or less east and west course and but little throw. They are displaced by what are called 'fault-veins,' like the Blue and Grey Rock which bear N.W. and S.E. Both these sets are faulted by veins having a N.E. and

S.W. direction, such as the Rarus, Original Diamond, and Leonard. In the E. and W. veins striated surfaces and clay selvages are not common, but in the fault-veins a gouge occurs along one or more planes of movement ¼″ to 6″ thick. Numerous other faults occur in the ground—mostly normal, but some reversed. The walls of some of the veins are not well-defined, the transition from the ore to the country rock being more or less gradual. In others the transition is sharp and definite. In the Anaconda ground the main vein aggregates 25 to 40 feet, decreasing to 5 feet at the east end of the St. Lawrence. The Colusa copper vein is from 10 to 40 feet wide with little barren ground. The Syndicate copper vein has often been 40 to 100 feet wide, although at intermediate points it may be only 5 feet. The Rainbow Silver veins—for there are two nearly parallel—vary in width from a mere seam to 20 or 30 feet. In places, ground up to 100 feet wide has been mined. The ore in the E. and W. veins is wider and more uniform in mineral character than that in the fault-veins, which occurs in shoots of irregular form, varying greatly in size, the largest being over 1,000 feet in length and over 2,000 feet in depth. The ground in the shoots is much wetter than in other parts of the veins.

The contents of the veins are in great variety. Quartz is the most abundant mineral, and the first to appear in the veins. The silver veins contain sulphide of silver, blende, pyrite, and a little galena. The gangue consists of quartz with rhodonite and rhodochrosite. In the copper veins the quartz averages about 55%. Barite and calcite occur sparingly. The commonest metallic minerals are: Pyrite, the most abundant and earliest of them, averaging about 16%; then chalcocite, enargite, bornite and cupriferous pyrite. Less abundant are tetrahedrite, tenantite, covellite, blende, and galena. There are also alteration products of zinc, iron, and lead. About 15% of the ore mined averages 12% copper, the remainder carries about 4.8%; arsenic and antimony are present in considerable quantities. A little tellurium is present. Zinc is very widely spread, and more abundant in the silver than in the copper veins; in some second-class ores it averages 2%; in some silver ores it has ranged from 2 to 40%. Lead is only about one-fourth of the

zinc in quantity; gold occurs in both copper and silver veins in small quantities, there being, on the average, about one part of gold to 40 of silver. The ores contain about 2¼ cents gold to each pound of copper.

In some silver veins, like the Alice and Lexington, the vein materials present a more or less banded arrangement, quartz being predominant. Other veins consist largely of country rock, with irregular ramifications of metallic and non-metallic minerals. The country rock adjoining the veins is altered in some places to sericite and quartz, in others to kaolin. There is a zone of impoverishment in both the silver and copper veins and a zone of enrichment; in the latter the higher sulphides occur; the former carries silver, but very little copper. Recently much has been written as to whether chalcocite is a primary or secondary mineral, or partly both, but the answer to that question cannot affect its primary origin. It need not, therefore, be considered here. Masses of brecciated enargite cemented by chalcocite show that the latter is the younger.

As already said quartz appears to be the first-formed mineral in these veins, then argentite, pyrite, and chalcopyrite, followed by blende and galena, and afterwards by quartz. Manganese oxides occur in the altered zone only.

These veins have, in all probability, been formed partly in cavernous spaces, but mainly by replacement. The great variations in the width of some of the veins, and the large inclusions of country rock preclude the idea of either open fissures or the differential fault-movements so often considered as necessary to the formation of the varying width of veins. The granite contains over 6% of lime and magnesia, probably all occurring as silicates. These might be acted on by a solution of alkaline carbonate and converted into carbonates of lime and magnesia which could afterwards be replaced by metallic minerals as already indicated. The absence of these minerals from the aplite may account for there being no copper in the veins in that rock. The silicate of alumina might also be attacked in some cases and not only the alumina, but the soluble silica, removed, which may account for the fact that there is less silica in the veins than in the granite.

The Tin and Copper Veins of Cornwall.[75]—The rocks in which the veins of these counties occur are either argillaceous beds called 'Killas,' of Devonian age, or granite of post-Carboniferous age, or igneous dykes still younger. The granite occurs in seven different areas, six of them surrounded by Devonians, the seventh (at Dartmoor) partly by Devonians and partly by Carboniferous rocks. The stratified beds have been highly tilted and have a quaquaversal dip around the granite bosses. The junction of the two rocks is usually very irregular, and they often become mixed in a remarkable manner. In Dolcoath mine, 1,440 feet below where the granite was cut, a large mass of slaty rock enclosed in the granite was met with. At Tincroft, granite was found for 26 fathoms from the surface, then slate was encountered; it continued to a depth of 84 fathoms, where the main body of granite was cut. Both granite and slate are much intersected by dykes of eurite, locally called 'elvan' courses. The results of four analyses[76] of Killas are given below:

	Polgooth Mine 100 fm. level	Dolcoath Mine 215 fm. level	Botallack Mine Surface	Camborne 160 fm. level
	%	%	%	%
Water Hygroscopic..	2.00	.48	.39	.94
Water Combined....	1.26	.67	2.74	2.18
Silica.....	50.92	67.32	40.22	67.82
Alumina.....	20.79	20.85	24.01	9.56
Ferrous Oxide.....	4.92	1.66	11.27	5.02
Ferric Oxide.....	13.41	2.83	4.21	Tr.
Lime.....	1.62	2.03	4.11	2.58
Magnesia.....	.....	Tr.	6.52	3.42
Potash.....	.93	.60	1.67	2.37
Soda.....	4.08	3.37	3.57	4.32

[75]For fuller information on this district see Report Geology of Cornwall, Devon and West Somerset by H. de la Beche, 1839.

[76]Rocks of the Mining Districts of Cornwall. By J. A. Phillips, Quart. Journ. Geol. Soc., Vol. XXXI.

Analytical results of granite and elvan are given on p. 350.

The principal tin and copper districts of the counties are on, or adjacent to, the granite areas. The Tavistock division is principally cupriferous. The St. Austell district is mainly stanniferous. The important district of Gwennap, Redruth and Camborne is chiefly cupriferous, except near the last-named place. Breague, Marazion, and Gwinnear yield both copper and tin. St. Just and St. Ives are mainly stanniferous. The veins occur in both granite and slate.

The tin and copper veins have a more or less easterly and westerly direction. In the Redruth District they bear about N.E. and S.W.; in the St. Austell District about N.W. and S.E. The lead and iron veins have a northerly and southerly bearing. The latter are the younger. They intersect and shift the east and west veins. The most productive veins occur within three miles on either side of the contacts between the slate and the granite. The elvan courses traverse both the granite and the slate, and are approximately parallel to the tin and copper veins, but are in some cases cut by the latter at acute angles. Some tin veins are in the elvan courses. Most of the ore in the principal veins in Gwennap (the great cupriferous parish of Cornwall), has been found in or near large elvan courses.

According to Henwood, the different veins have the following average widths:—

	Feet
Those containing tin and copper ores.....	4.7
" " tin ore.....	3.0
" " copper ore.....	2.9

They are wider in slate than in granite, and are wider down to 600 feet than below that depth.

Some of the lodes are nearly vertical, but the mean dip is about 70° from horizontal. Inclusions of country rock occur in the veins which often graduate into the surrounding vein-stone. The bedding planes of inclusions are always parallel to those of the enclosing rock, except in the case of small pieces. In granite the vein-stone is usually felspar, imperfectly crystalline, quartz

and schorl. In slate, quartz is the predominant non-metallic mineral with quartzose slate, chlorite and schorl. Fluorite is not uncommon in the deep. Some veins in the slate, like Fowey Consols, include pyrite and siderite among their more frequent constituents. The copper veins are altered on their backs in some instances to considerable depths, and at increasing depths oxides, carbonates, and the higher sulphides appear before chalcopyrite comes in. At Fowey Consols, the weathered ground extended about 700 feet below the surface, at Dolcoath about 1,100 feet. These depths are not only much below the ground-water level, but also far below the neighbouring sea level, the weathering having probably taken place when the ground stood much higher.

Some of the veins that contained tin near the surface afterwards changed into copper veins for some depth, and then became tin-bearing again. Henwood states[77] that one of the veins at Botallack passed three times from granite to slate, and in each case it contained tin only in the former, and copper only in the latter. The occurrence of tin in the granite and copper in the slate is usual in the St. Ives Mines.

Of associated minerals, blende is more frequently found with copper than with tin. Arsenopyrite, pyrite, and wolfranite are common in tin veins, with some chalcopyrite. Veinlets of tin-ore are often found in slates adjoining veins. They are supposed by some writers to be filled fractures. An illustration of such veinlets from St. Agnes is given by de la Beche[78] and shown in Fig. 32. A critical study of it soon convinces one that they are not filled fractures, but replacements along lines of jointing.

All veins—tin, copper or lead—are most productive on their more highly inclined portions. The explanation of this fact is probably as follows: Veins that alter much in their dip cannot have had any differential movement vertically. Some slight movement laterally would produce a passage for underground waters, which would flow much more freely in the steep parts of the vein than in those that were less inclined, and therefore, deposit more ore in them because the effect of lateral movement

[77]Metalliferous Deposits of Cornwall and Devon, 1843.
[78]Report of Geology of Cornwall and Devon, etc., pp. 316-7.

in widening a fracture would be most pronounced in the steepest parts of the veins. To take an extreme case, if part of a vein were vertical, a movement laterally of half an inch would produce an opening of that width; if another part were horizontal, the opening there would be nil, by that or any other probable amount of lateral movement, and generally the opening formed by any given movement laterally would be directly proportionate to the inclination as shown in Fig. 34.

The ore-shoots, or bunches, as they are locally called, have frequently a pitch lengthwise of the vein, which, in the granite, is approximately parallel to the jointing; in the slate, to the bed-planes. In the Western Division the ore-shoots dip *from* the granite; if in that rock they dip *towards* the slate. Frequently the bunches are as shown in Fig. 35, which is a projection on a vertical plane of part of the Dolcoath vein. Between the 130 and 180 fathom levels the vein was poor, but below the latter depth quantities of cassiterite have been worked.

Many of the veins are on the lines of faults, but some are as certainly not. An interesting horizontal section, at the 100 fathom level of the vein worked by the East Huel Lovell Mine, in the parish of Wendron, is given by C. le Neve Foster[79] and is reproduced in Fig. 36.

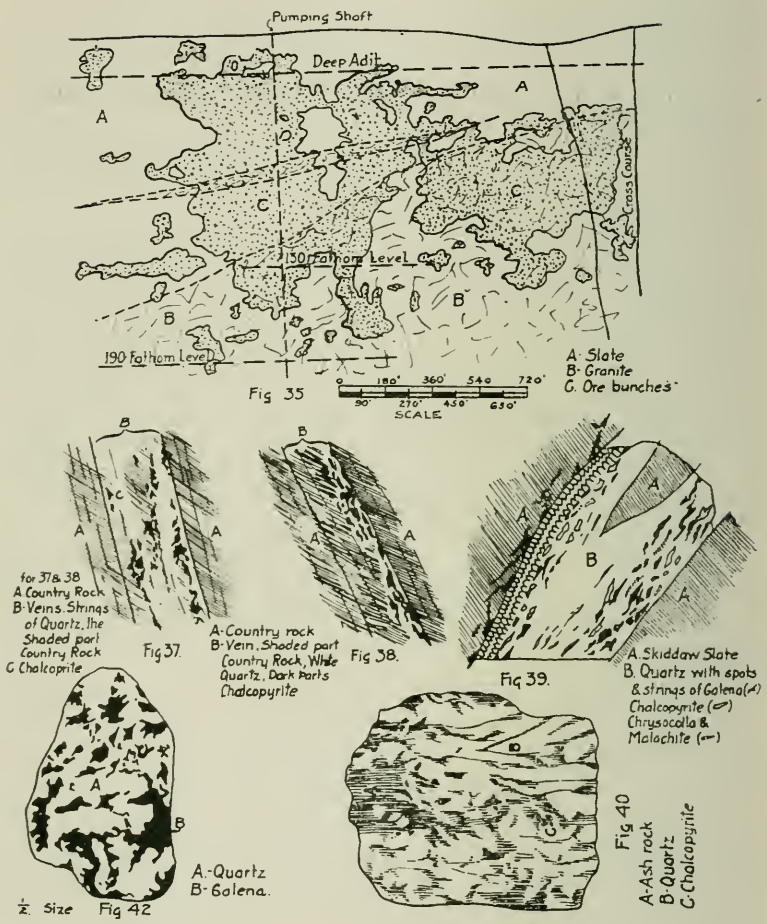
The 'carbonas' at St. Ives Consols are similar impregnations in the granite. Both at East Huel Lovell and at St. Ives Consols the orebodies gradually merge into the granite.

Caverns are sometimes met with in these veins. One which occurred in the Dolcoath mines at a depth of 1,020 feet is said to have been 100 to 120 feet long, 18 feet high and from 4 to 9 feet wide. In the lower part fragments of rock were wedged together between the walls.[80]

The comb structure of some parts of the veins has already been referred to.

A curious fact is mentioned by de la Beche[81] in connection with the Dowgass mine near St. Austell. A tin vein occurred

[79]Trans. Roy. Geol. Soc. of Cornwall, Vol. IX, p. 167.
[80]J. Rule, Roy. Geol. Soc. of Cornwall, Vol. I, p. 225.
[81]Geology of Cornwall, Devon and West Somerset.



on a contact of elvan and slate. Great quantities of tin ore were raised from the vein. Another vein occurred on the other side of the elvan "and it generally happened that when a good bunch of tin was found on one side they also found one on the other opposite to it." This was most probably owing to the fact that the wall-rock on opposite sides of the elvan course, where the ore formed, would be of the same character.

A decomposed on 'plumb' granite is considered to be such more favourable for mineral than a hard one. Soft slaty beds are also preferred to those that are hard.

The idea of filled fissures is not supported by the facts above given. Even the Dolcoath cavern could not be accounted for by differential fault-movements, much less the occurrence of ore-shoots along the lines of particular beds, as at Fowey Consols and as at Dowgass mine. The facts presented by Fig. 15 are also in opposition, as well as other facts which are common to all veins and are referred to in the general argument.

Mineral Veins of the English Lake District[82] *and Alston, Weardale, etc.*—The rocks of the Lake District, in which the principal mineral veins are found, are either the argillaceous beds of the Skiddaw slates, the Eskdale granite, the Ennerdale granophyre, or the ash beds of the volcanic series of Borrowdale. The chemical composition of some of these rocks is as under:—

	Skiddaw Slate	Eskdale Granite	Ash Rock
	%	%	%
Silica	57.76	71.44	69.54
Alumina	24.91	15.34	15.17
Ferric Oxide	6.07	1.23	.30
Ferrous Oxide	..	1.10	2.81
Lime	.64	1.06	2.15
Magnesia	1.32	.72	.55
Potash	3.31	4.43	3.94
Soda	1.66	3.95	4.32
Phosphoric Acid	..	.11	.27
Loss on Ignition	4.86	.58	.76
	99.53	100.00	99.31

[82]The Mineral Veins of the Lake District, by J. D. Kendall. Trans. Manchester Geol. Soc.

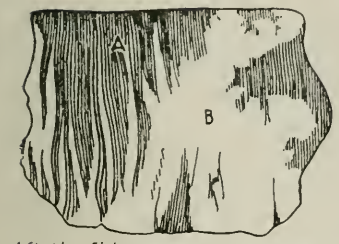
The Skiddaw slates are the oldest rocks of the district. They are overlain by the volcanic series of Borrowdale, followed by the Coniston series, the Bannisdale slates, and the Kirkby Moor flags. All these rocks were uplifted, tilted, and much denuded during the Devonian period. The Carboniferous rocks form an irregular ring round them, resting on a plane of marine denudation with a quaquaversal dip, due to the further uplifts which took place at the close of the Carboniferous period, and again (at an uncertain date) since the close of the Permian period. It was probably during the first of these uplifts that the Eskdale granite and the Ennerdale granophyre broke through the Skiddaw slates and the Borrowdale rocks. The greatest number of veins are in the Skiddaw slates. The age of these veins cannot be determined from any known facts, but they are probably younger than the Carboniferous.

The copper veins have a more or less easterly and westerly course, and dip southward. The iron and lead veins bear—as in Cornwall—in a northerly and southerly direction and dip eastward. The structure of some of the veins is shown by Figs. 37 and 38. The former is a vertical section of Benson's South vein, Tilberthwaite, and the latter a section of Paddy End vein, Coniston. A section of Red Gill vein, which carried both lead and copper, is given in Fig. 39.

The manner in which the country rock forming part of the veins is split up by quartz, is shown by Fig. 40—a section seen in the Bonsor vein, Coniston. In the lead veins we find similar occurrences one of which, as seen in Yewthwaite mine, near Keswick, is recorded in Fig. 41.

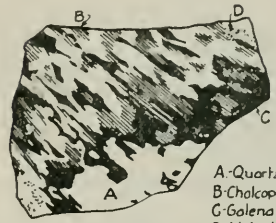
The occurrence of the metallic minerals amid quartz and country rock is represented by Figs. 42, 43, 44, and 45.

Interesting sections of dolomite traversing silicate rocks are sometimes met with. Fig. 46 shows one seen in the Brandlebow mine, near Keswick, the country rock being Skiddaw slate. Fig. 47 represents part of a vein near Boot, in Eskdale. There the country rock is granite. Fig. 27 shows veinlets of dolomite in ash rock. In both 47 and 27 hematite occurs, replacing dolomite.



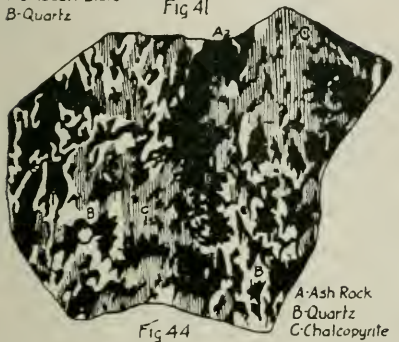
A-Skiddaw Slate
B-Quartz

Fig 41



A-Quartz
B-Chalcopyrite
C-Galena
D-Malachite

Fig 43



A-Ash Rock
B-Quartz
C-Chalcopyrite

Fig 44

Fig 45
A-Skiddaw Slate
B-Galena
C-Limonite

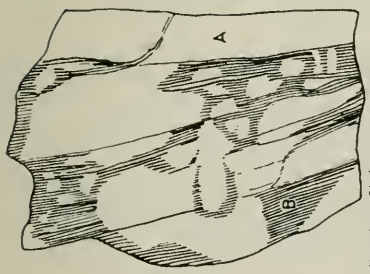


Fig 46
A-Skiddaw Slate
B-Dolomite

Fig 47
A-Eskdale Granite
B-Dolomite
C-Hematite

The principal minerals in the copper veins are quartz, chalcopyrite, and pyrite, in some cases with alteration products of the two latter. Pyrrhotite, magnetite, calcite, and dolomite also occur in them. In the lead veins, galena, blende, pyrite and their alterations are the most important metallic minerals. These veins also carry dolomite, calcite, and barite. In some of the hematite veins stalagmitic and stalactitic hematite occurs in small loughs, and laminated ore is frequently seen on and

adjoining the walls. Small fragments of wall-rock—not exceeding half an inch across—are occasionally found in the ore.

Figs. 37, 38, and 39 are quite irreconcilable with the idea of filled fissures. A still more striking piece of evidence against that idea is presented by Fig. 48, which is taken from the writer's paper on the Hematite Deposits of West Cumberland.[83]

The Alston, Weardale, and Allendale veins are in Yoredale[84] rocks, which are alternations of limestones, sandstones, and shales, having a total thickness of 950 feet to 1,200 feet. There are 11 beds of limestone, ranging from 18 inches to 63 feet, and aggregating about 183 feet in thickness. The most important bed—known as the 'Great Limestone'—is about 63 feet thick (varying from 36 to 68 feet); it has probably yielded as much lead as all the other beds together. The aggregate thickness of the sandstones is about 320 feet. Near the base of the series is an intrusive sheet of basalt—known as the 'Whin Sill.' It occurs in some places above the Tyne bottom limestone, in others below it. Its thickness is variable—at Caldron Snout it is about 175 feet thick; at Burtree Pasture mine, 236 feet; at Dufton Fell it is only about 45 feet.

There are two principal sets of veins, one approximately east and west, the other within a few degrees of north and south. The latter are the younger and intersect the east and west veins. Both sets carry lead ores, but the east and west veins are the more productive.

The evidence furnished by the veins of these districts tells a similar story to those of the Lake District, but here the existence of several well-defined beds of limestone enable us to determine closely the throw of the faults along which the veins occur, and to test the alleged influence of differential movement on the varying width of veins. In some of the veins the differential movement has been only a few inches, in other 15 to 100 feet, and, in one case, as much as 260 feet, although only 42 feet at a point 2¾ miles away. A differential movement exceeding 24 feet puts all the limestones, except the Great and the Scar, into opposition

[83]Trans. N. of E. Inst. of M. and M.E.'s, 1879.

[84]The Strata, by W. Forster, 1821; and Mineral Deposits, by Wm. Wallace, 1861.

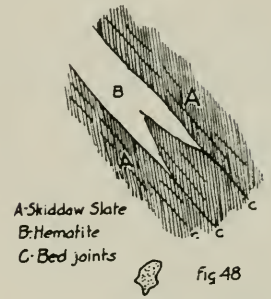


Fig 48

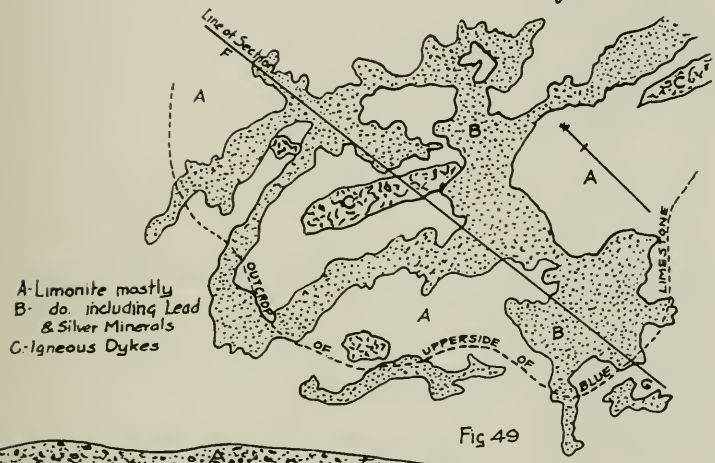


Fig 49

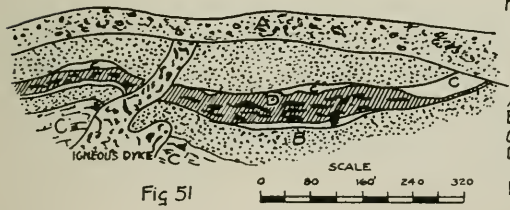


Fig 51

with shale or sandstone. The most productive veins are those with a small throw, so that the limestones remain in opposition almost throughout the full thickness of the beds, and the widest parts of the veins are invariably in the limestones.

The shale beds are not productive of metallic minerals except in the case of strong veins carrying 'rider' (veinstone). Strings of galena are occasionally found in sandstone, but limestone is by

far the most productive of ore. It is not uncommon to see a vein in the sandstone only a few inches wide, whilst in the limestone it may be 3 or 4 feet. The Long Cleugh vein contained a considerable quantity of galena in the firestone, a siliceous bed about 33 feet thick. Some veins contain ore only where the opposite sides are limestone.

'Flats' of ore branching off from some of the veins occur in the 'Great Limestone,' the Scar Limestone, and the Tyne Bottom Limestone. These strata are split up by thin beds of shale into high, mid and low flats. The ore in the flats does not extend to a great distance from the veins. At Small Cleugh they have been worked over an area of about three acres in the 'Great Limestone,' mainly in the low flat post, which is about 15 feet thick.

The veinstone—locally called rider—may consist of calcite, fluorite, quartz, barite or witherite, siderite and limonite, or some of them, the most abundant being the two first. In Wellhope vein barite occurred in the upper beds of sandstone and witherite in the 'Great Limestone.' In the Hampgill and Middle Cleugh veins, barite occurs in the Grindstone sill, but not in any of the strata below. The ores of iron have, in some cases, as at Nest, Manor House and Lowlyer House, near Alston, been so abundant as to be shipped to the iron furnaces. At Rowantree mine in Weardale, siderite and limonite, spotted with galena, were worked for the iron after the main body of lead ore had been removed. The iron ores graduate into the limestone. From some old mines, ore that had been stowed away in the stopes was sent to the furnaces. The 'Great Limestone' and the 'Scar Limestone' have yielded most of the iron ore. The siderite—or white, or grey ore, as it is locally called—contains numerous cavities called 'lochs' or 'loffs,' which are lined with crystals of one or more of the following minerals: siderite, quartz, calcite, fluorite, dolomite, etc. Some of the loffs, which originally existed in the ore, appear to have been subsequently filled, or partially so, by siderite, which has invested the fluorite and other crystals that had previously formed on the walls of the loffs. Both the siderite and its alteration product (limonite) have a considerable quantity of galena scattered through them in places, where the

veins happen to be lead-bearing. In other parts they are quite free from that mineral. In some places galena occurs as solitary cubes in the siderite, but more frequently in irregular interfering aggregations of such forms.

Along with galena, blende and pyrite occur in variable quantities. In some places cerussite is found, at others a little chalcopyrite. Inclusions of limestone frequently occur in the veinstone when one or both of the walls are limestone, but not otherwise. In places the veinstone occurs as a rib, from a few inches to 5 or 6 feet in width, with good lead ore occurring interruptedly on one or both walls of the vein, and more or less galena scattered through the veinstone. In other cases there are two such ribs. The North Hudgill Burn vein was about 17 feet wide in the Great Limestone, with four ribs of galena, each 2 to 4 feet wide. Facts relating to the order of deposition have already been given.

In this field, as some of the foregoing facts show, there is very clear evidence that differential movements have nothing to do with the widening and narrowing of veins. No matter what the extent of the throw, the veins are always wider in the limestone than in the intervening sandstones and shales. It will be generally admitted that differential movements are not sufficient to account for the flats. Why then should they be invoked in explanation of variations in the width of veins, for flats may be looked upon simply as extraordinary widenings of the veins at those particular levels. The character of the vein-filling is also opposed to the idea of open fissures, the inclusions of limestone in the gangue being confined to those parts of the veins that are in limestone. If the veins had been filled, open fissures, blocks of limestone might have been met with anywhere.

The formation of these veins probably began with a solution of sulphate of iron attacking the limestone along lines of fracture and faulting, carbonate of iron being substituted for carbonate of lime, and sulphate of lime carried off in solution. The volume of carbonate of iron precipitated would be less than the limestone removed in the ratio of 1.26 to 1, so that there would be a number of cells, cavities or cavernous spaces formed in the siderite. Into these some of the different metallic and non-metallic minerals

could be deposited at various times and in the order already alluded to on p. 345. Much of the lead, no doubt, is a replacement. The sandstone beds might be attacked by dissolution of the interstitial cementing material and also by action on the siliceous particles, but, offering greater resistance than the calcareous beds, they have not been removed to anything like the same extent.

In the lead mines of Swaledale, in Yorkshire,[85] we find corroborative evidence. The rocks there also belong to the Yoredales, and have an aggregate thickness of about 1,000 feet, including 8 beds of limestone and 4 beds of chert, which aggregate about 300 feet. The principal limestone is known as the 12-fathom limestone. There are about 170 productive veins in the dale, of which 65 have a throw under 6 feet, 26 under 12 feet, 21 under 18 feet, 12 under 24 feet, 5 under 30 feet, 8 under 36 feet, 1 under 42 feet, 4 under 48 feet, and so on for the remaining 28. The veins with a small throw are the most productive of lead-ore, and the greater portion of the lead-ores raised has come from the Main, or 12-fathom limestone.

Neither in Swaledale nor in Alston, Weardale, or Allendale are there any igneous rocks from which the lead-ore could have been derived except the Whin Sill, which is 430 to 470 feet below the Great Limestone, the most productive lead-bearing stratum in those districts; but there is much faulting and consequent fracturing by which the metallic vapours could find their way from the barysphere to the water zone of the lithosphere.

Bed Deposits

The Kupferschiefer of Mannsfeldt, Germany.—This bed occurs in the Permians, near the base of the Zechstein series. It is about 15 to 18 inches thick, is underlain by the Zechstein conglomerate and calcareous sandstone, and overlain by the Zechstein, a thin bedded argillaceous limestone, which extends over a large area, and is extensively worked at Manns-

[85]The Mineral Veins of Swaledale, Yorkshire, by Lonsdale Bradley, 1862.

feldt on the S.E. extremities of the Hartz Mountains. It also occurs in the Thuringian Forest and at Hermannseifen in Bohemia. It consists of black bituminous shale interleaved with thin layers of copper ores, chalcopyrite, and bornite, in places chalcocite, and some silver as argentite. These layers are frequently accompanied by gypsum. Associated subsidiary minerals are blende, galena, and pyrite. No part of the vein is barren of copper, but some parts are much richer than others. The thickness of the most productive part ranges from 2½ to 5 inches of the lower part of the bed, and contains 2 to 3 per cent copper and 4 to 5 oz. silver per ton. A. von Groddeck[86] says: "Small bodies of chalcocite occur in the limestone above the bed." The following analytical results are of samples from different parts of the bed:—

	%	%	%
Silica	38.42	33.15	29.22
Alumina	15.93	12.90	11.76
Lime	10.93	14.39	12.66
Magnesia	3.53	2.32	2.25
Iron	1.81	3.31	2.97
Copper	2.01	2.90	2.88
Silver	.015	.016	.021
Sulphur	3.18	2.15	4.97
Carbonic Acid	7.02	10.47	9.43
Bitumen, by loss	14.63	9.89	17.21

Lead, zinc, nickel and cobalt determined only qualitatively.

The bed is much faulted, and copper is more abundant near the faults than farther away. Regarding this feature B. von Cotta[87] wrote: "The fault fissures themselves, however, are rarely ore-bearing, yet often seem, nevertheless, to have influenced the ore-bearing character of the strata traversed by them. This influence is shown in the increase or diminution of the proportions of ore, not only in the immediate neighbourhood, but sometimes also for a considerable distance, even as far as the

[86]Die Lehre von den Erzlagerstätten, 2nd Ed. Freiberg, 1859, p. 85.
[87]Die Lehre von den Erzlagerstätten der Erze. Ein Zueig der Geologie. Leipzig, 1879.

next master-fault. It is shown also in the transfer of the metallic contents from one stratum to another." He further says: "Near Camsdorf it is almost exclusively where the Kupferschiefer has suffered such disturbances that it is rich enough to repay mining."

These ores are probably replacements of part of the calcareous portion of a bituminous limey shale, the mineral solution which effected the replacement having come from below along the lines of faulting. The occurrence of chalcocite in the limestone above the orebed is strong evidence in favour of replacement.

The Blackband and Clayband Ironstones of Scotland and North Staffordshire.—These ironstones occur as beds in the carboniferous rocks. In Scotland they are partly in the carboniferous limestone and partly in the millstone grit and coal measures. In Lanarkshire the following seams of ironstone occur in the coal measures:—[88]

NAME OF IRONSTONE	AVERAGE THICKNESS fms.	ft.	in.
Palace Craig. Blackband of local occurrence at Palace Craig and Faskine			9
Strata, including upper Ell, Pyotshaw, Main, Humph, Splint and Vergen Coals	76	0	0
Airdrie. Blackband 12″ to 18″		1	4
Strata	16	0	0
Newarthill and Clelland. Roughband 2″ to 8″			6
Strata 9″ to 12′, including Virtuewell Coal.	1	3	0
Bellside. Ironstone 5″ to 9″ a local seam			6
Strata 11 to 13 fms	12	0	0
Kiltongue. Musselband and oil shale		1	3
Strata, including Kiltongue, upper and lower Drumcray Coals	58	0	0
Upper Slaty. Blackband 0 to 3½ feet		1	2
Strata	16	0	0
Lower Slaty. Blackband 0 to 8 feet		1	10

[88]Geol. Sur., Explanation of Sheet 31.

Some of the seams are much more limited in area than others. The slaty band, at the base of the coal measures, although very variable in thickness, occurs over an extensive area, having been worked, under different names, in the Falkirk, Dalmellington, Lugar, and Muirkirk districts.

In the millstone grit, near Greenburgh, there are two seams of clay ironstone, one known as the Ginstone, the other, about 30 fathoms lower in the formation, as the Curdly ironstone. On the western boundary of the Falkirk coalfield there is a seam of clay ironstone so calcareous that it can be used as a cement.

The Carboniferous limestone is divisible into three parts. In the Carluke district the uppermost portion—about 51 fathoms thick—contains three beds of limestone separated by beds of sandstone. The middle part—28 fathoms thick—contains no limestone, being made up of sandstones and shales with various coals and clay ironstones. The lowest part of the series—in a thickness of about 93 fathoms—contains 15 beds of limestone separated by sandstones and shales in which are two seams of coal and some beds of clay ironstone. Some of the lower limestones rest directly on coal. In the middle part of the series, in the Kilsyth district, there are four seams of blackband ironstone, as under :—

			Thickness ′ ″
No. 1	Blackband:	Coal, ironstone and partings	1.2
No. 2	"	Crawcoal and ironstone	.8
No. 3	"	Coal and ironstone	1.6
No. 4	"	Banton	1.2

These ironstones are very variable in thickness and quality. No. 1 dies out to the West. No. 4 is also local. Attention is called to the fact of these blackbands being associated with coal, also to the fact, stated above, of some of the limestones resting directly on coal.

In the Glenbuck and Muirkirk district[89] the middle division contains four clayband ironstones from 12″ to 15″ thick, the three

[89]Geol. Sur., Explanation of Sheet 23.

uppermost being known as the high, mid, and lowbands respectively, the lowest as the McDonald. In the lower division two ironstones occur, known as Smith's and Crossflat respectively. In the Muirkirk section a blackband 10″ thick occurs, about 4′ below the Ell coal, in addition to the four claybands mentioned in the middle division of the Glenbuck section. In the Dalry mineral field there is, in the lowest division, a blackband about 15″ thick, and about 32 fathoms lower a seam of clay ironstone 13″ thick. The blackband is interstratified with and sometimes completely replaced by igneous rock.

Some of the iron seams become very calcareous. This seems to be particularly so on an abnormal thickening of the stratum. In some cases the seams have been traced into coal.

The fossil contents of the ironstones are similar to, but much less abundant, than those in the limestones. They differ from those rocks, however, in the blackbands containing plant remains, which occur in the carbonaceous matter.

The blackbands are lighter than the claybands, as shown by the following specific gravities:—

	Specific Gravity
Nethercray clayband	2.81
Dalry "	3.22
Dalry blackband	2.21
Cadder "	2.21
Slaty "	2.69

Faults are numerous, and igneous rocks are met with frequently. In some cases they are interbedded, in others they occur as intrusive sheets or dykes.

The large quantity of lime and manganese in some of these ironstones is shown by the following analytical results:—

	Blackband %	Clayband %
Protoxide of Iron	41.65	24.90
" Manganese	.....	1.22
Silica	.52	6.80

	Blackband %	Clayband %
Alumina	.96	3.27
Lime	5.76	16.55
Magnesia	3.52	7.54
Carbonic acid	33.08	35.61
Phosphoric acid	.84	1.76
Sulphur	.25	.31
Iron combined with sulphur	.22	.27
Bituminous matter	11.16	.73
Water	2.04	.52
	100.00	99.48

If the bituminous matter and the attendant water in the blackband were removed, the percentage of lime and magnesia would be still higher.

The ironstones of North Staffordshire occur in the southern part of the coalfield, the blackbands in the measures above the Peacock coal and the claybands in the upper part of the measures below that coal. The principal blackbands at Apedale are:—The Blackband, which has an average thickness of 18″; the Red Shag, ranging from 1′ to 5′; and the Red mine, from 2′ 6″ to 9′ 0″. Each is underlain by a coal seam. Minute crystals of galena and blende occur sparingly through the Red mine.

At Great Fenton, Shelton and Lane End, the Bassy mine is worked. It varies in thickness from 1′ to 6′, and is underlain by coal from 18″ to 3′ 0″ thick. Like most blackbands it is striped by black carbonaceous markings. Thin layers of pure coal $\frac{3}{16}$″ thick, and over, are occasionally seen in the ironstone, parallel to the bedplanes, in some cases as much as 6″ above the coal seam on which the ironstone reposes; but there is no connection by cross joints. The extent of the ironstones on any given horizon is very limited. Taking the localities above-named, the same seam probably does not occur in any two of them if we except the Bassy mine of Shelton and Lane End. The

specific gravity of the ore ranges from 2.34 to 2.52, its chemical constitution, as well as that of the Red mine at Shelton, being as under:—

	Bassy Mine	Red Mine of Silverdale
	%	%
Peroxide of iron	5.06	1.01
Protoxide of iron	45.53	34.22
" manganese	1.74	2.87
Silica	1.36	3.13
Alumina	.74	1.35
Lime	2.91	11.91
Magnesia	2.13	1.44
Potash	.05	Tr.
Carbonic acid	32.12	32.52
Phosphoric acid	.86	.87
Sulphuric acid	.08	.12
Bisulphide of iron	.37	.35
Organic matter	2.29	.75
Water-combined		.23
" hygroscopic	5.20	8.93
	100.44	99.70

The percentage of lime and magnesia would, of course, be higher if the bituminous matter were removed.

The thickness of the ironstones varies inversely to that of the underlying coal; when the ironstones are thickest the coals are thinnest, and *vice versa*. As regards quality, the seams are divided into tops, middles, and bottoms, the tops being the poorest, the bottoms the best.

A few organic remains, similar to those found in the limestones, of the Carboniferous system, and also plant remains, are found in the ironstones.

The large amount of lime and magnesia in these ironstones, as well as in those of the Carboniferous rocks of Scotland, suggests

that the beds were originally bituminous or argillaceous limestones which were replaced by double decomposition of the carbonate of lime and some iron-bearing solution. The better quality of the iron occurring immediately on the top of the coals and its decreasing quality upwards as the siliceous and aluminous conditions, afterwards prevailing, were gradually coming on, is quite in harmony with this idea.

It will be noticed that, however different the percentage of iron may be in these ores (and this applies to Scotland as well as to North Staffordshire), the percentage of carbonic acid does not vary much, while the sum of the oxides, among which the carbonic acid would be divided to form carbonates, is nearly the same in each case, as shown below:—

	Scotland		North Staffordshire	
	Blackband	Clayband	Blackband	Clayband
Protoxide of iron..	41.65	24.90	45.53	34.22
" manganese	..	1.22	1.74	2.87
Lime.....	5.76	16.55	2.91	11.91
Magnesia.....	3.52	7.54	2.13	1.44
	50.93	50.21	52.31	50.44
Carbonic acid....	33.08	35.61	32.12	32.52

If these ores are not replacements of bituminous limestones, it is a most extraordinary coincidence that the reciprocal relation of the metallic and non-metallic oxides should be such as it is. Seeing that the ironstones occur among rocks which are mainly siliceous and aluminous, we might fairly have looked for much larger percentages of silica and alumina in association with the iron and very little lime and magnesia.

The reduced number of fossils in the ironstone as compared with the limestone is what might be expected, as many of them would no doubt be destroyed in the process of replacement. The districts in which the ironstones occur is perhaps the most faulted part of the fields.

Irregular Deposits

This division includes a great variety of orebodies; among them, contact deposits, in some cases bed-like, in others vein-like; the cavern-like deposits occurring entirely in calcareous rocks, such as the hematite deposits of Cumberland and Lancashire; the copper deposits in the carboniferous limestone of Arizona; the lead-ore bodies of Wisconsin and Missouri; and the huge masses of hematite in the silicate rocks of Lake Superior and Brazil.

The Silver-Lead Deposits of Leadville.[90]—These important orebodies occur in two dolomitic limestones. The upper limestone, locally called the 'blue limestone,' is about 200 feet thick. It is part of the Carboniferous system and is overlain by intrusive igneous rock—called 'white porphyry'—which varies in thickness from a few feet to about 1,500 feet at one point. The limestone is underlain in most parts by quartzite, about 40 feet thick, but in some cases by white porphyry. Beneath the quartzite is another bed of dolomitic limestone—known as 'the white limestone'—about 160 feet thick, and of Silurian age. It rests upon what is locally called the 'lower quartzite'—150 to 200 feet thick. The white limestone is thin bedded, the different beds in the lower part being separated by layers of shale, of an inch or more in thickness.

The aqueous rocks are conformable throughout. They are frequently intersected by faults of extension, some of considerable throw, and have also been subject to increased lateral pressure by which they have been thrown into numerous rolls and intersected by reversed faults. The white porphyry, after being forced through the underlying rocks to the top of the blue limestones, has spread out over a very large area, between that rock and the Weber shales, which once rested on the blue limestone. In fact at several places there is still a thin layer of these shales on the limestone and under the porphyry. Other igneous rocks, younger than the white porphyry, have also penetrated the strata. The grey porphyry rests on the white porphyry over an extensive

[90]Geol. and Mining Industry of Leadville, U.S. Geol. Sur.

area. It has also been forced into both the white porphyry and the blue and white limestones at numerous points, and in many directions—long tongue-like protrusions along and across the bed-planes of the blue and white limestones being of common occurrence.

The orebodies occur partly along the contact of the white porphyry and the blue limestone, and partly in irregular bodies in other parts of that limestone, as well as in the white limestone, particularly in association with the grey porphyry. As seen in plan, the longer axes frequently have an easterly and westerly direction, as shown in Fig. 49, which is a plan of one of the orebodies in the blue limestone on Fryer Hill, after C. M. Rolker.[91] In other cases the direction is determined by a fault-plane or by a dyke as in Fig. 50, which shows the ore-deposit at the fifth level of the Tucson Mine in the white limestone on Iron Hill, after G. A. Argall.[92]

The variations of direction in the different orebodies when not interfered with by faults or dykes range from 80° N.W. and S.E. to 80° N.E. and S.W., corresponding to one of the sets of joints in the limestone. The appearance of the orebodies represented in Figs. 49 and 50, when seen in vertical section, is shown by Figs. 51 and 52 respectively.

The upper surface of those parts of the orebodies when in contact with the white porphyry is more regular than the under surface, which, in places, extends downwards to the bottom of the limestone; whilst in other places it may not be many feet below the white porphyry. Some of the orebodies occur down in the limestone, away from the white porphyry altogether, but in contact with the grey porphyry, as shown in Fig. 53, which is a cross section of the orebodies on Iron Hill, after A. A. Blow.[93]

Some small deposits of ore occur as encrustations of widened joints in the lower quartzite. The orebodies in the blue limestone consist to a large extent—in the zone of oxidation—of hydrated peroxide of iron with some manganese or ferric sulphate

[91]Notes on the Leadville Ore-Deposits. Trans. A.I.M.E., Vol. XIV.
[92]*Engineering and Mining Journal*, 29th January, 1910.
[93]Geology of the Ore-Deposits of Iron Hill, Leadville, Colorado. Trans. A.I.M.E., Vol. XVIII.

in which are numerous inclusions of limestone. Through the iron ores the lead and silver ores are scattered in a very irregular manner, as shown in Fig. 46. These latter minerals occur partly as argentiferous galena, but mainly as its alteration products—cerussite and cerargyrite. Anglesite, pyromorphite, chlorobromide and chloroiodide of silver are also found, as well as some gold and quartz. There is more gold in the ores of Breece Hill, Printer Boy Hill, Florence Hill, and Little Ellen Hill than in the western part of the district, the silver being a secondary feature, the gold representing about 80% of the net value of the ores. Small quantities of pyrite, copper, bismuth, molybdenum, vanadium, cobalt, etc., are also found. Very little zinc occurs near the surface, but it increases downwards, appearing as calamine; as the lower limit of the zone of alteration is approached the lead occurs more extensively as galena, and the silver probably as argentite. Below the zone of alteration the ores are pyrite, galena, and blende, each with its quota of gold and silver, and some quartz. The proportion of blende has increased very much downwards. Its comparative absence from the upper reaches of the deposits is doubtless due to its solubility when altered to the sulphate.

In the white limestone the orebodies consist of pyrite, blende, and galena, with a small percentage of chalcopyrite. The gangue minerals are silica and clay. The thin layers of shale between the beds of limestone extend into and through the ore.

The lead ore was in all probability deposited as a sulphide, kernels of that mineral being frequently found in the carbonate ore. The silver also was probably a sulphide originally. The iron may have been deposited as a carbonate, afterwards altered wholly or partly into pyrite, from which the limonite and the ferric sulphate were produced, the carbonate being substituted for the limestone. In consequence of the reduction of volume resulting from the replacement, a number of cavities of various shapes and sizes would be formed throughout the siderite or pyrite into which some of the lead, silver, and other minerals could be deposited later—either before or after oxidation of the iron. The remainder of the lead is probably the result of replacement.

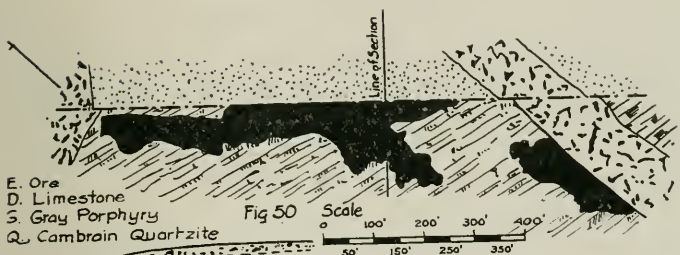


Fig 50

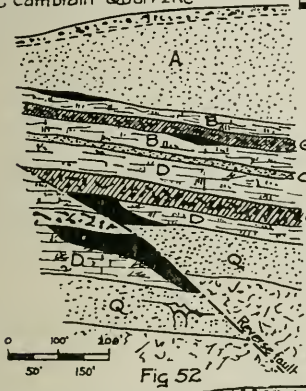


Fig 52

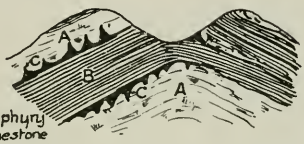


Fig 54.

A. Limestone
B. Schist
C. Ore.

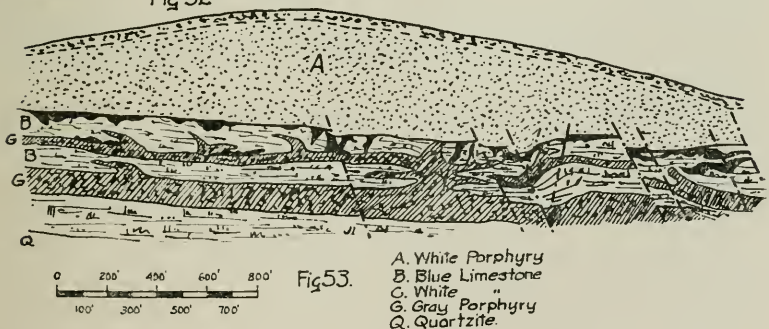


Fig 53.

A. White Porphyry
B. Blue Limestone
C. White "
G. Gray Porphyry
Q. Quartzite.

Posepny thinks these ores were deposited in caverns. In so thinking he must have overlooked the everyday experience of miners of the impossibility of keeping up the roof of such extensive cavernous spaces. In the north iron-shoot of Iron Hill there would have had to be at least one space of 250 feet square without any intermediate support, which I think will at once be pronounced impossible by all practical miners. Nor could the

thin layers of Weber shale, which (according to Emmons) occur in places over the ore, have remained in position even over a very much less space than that mentioned above. At the time Posepny wrote, ore had not been found in the white limestone. The thin layers of shale in that ore which are also interbedded with the limestone are conclusive as to replacement.

Emmons looks upon the deposits as replacements, but thinks the source of the ore was the igneous rocks of the neighbourhood. He does not agree that they could have been brought direct by solutions from heated regions below, because he could not "find any convincing evidence of ascending solutions.... wherever the form of the orebody was such as to throw any light upon the probable direction of the ore-forming currents, it showed that they must have descended, for they all terminated more or less in a point or wedged out downwards." In this connection I reproduce in Fig. 54 a drawing, after Huot, of an orebody at Laurium, in Greece.

Here we find the ore wedging out, as Emmons expressed it, both upwards and downwards. To my mind the explanation is that the solution which affected the replacement flowed along the two contacts, and worked upwards and downwards along intersecting joints in the limestone, the result of which must be a more or less conical or wedge shaped body, because the action of the solution would be greatest at the base and least at the apex.

The wedging out of orebodies downwards is a common occurrence. I have seen it in all the deposits in limestone I have examined in many different mining fields. It is not improbable that it is due, in many cases, to the strengthening of solutions upwards as they cooled, the obtuseness of the wedge depending upon the rapidity of cooling. At 176° F. water can only dissolve .2226 per cent of chlorine, but at 68° it can dissolve .7291 per cent, so that a chloride, formed by the union of a metallic vapour and a solution of chlorine, would become gradually stronger upwards as the solution cooled, and would therefore deposit a gradually increasing quantity. If the volume of the ascending solution were small, and its temperature had not cooled down to about 200° F. until it passed into rocks that had

a very much lower temperature, its further cooling would be rapid, consequently its capacity to dissolve an increasing quantity of metal or metallic mineral would for a time become greater and greater, and the quantity of ore deposited would increase correspondingly upward.

The Hematite in the Carboniferous Limestone of Cumberland and Lancashire.—The principal iron-ore deposits of the Cleator District occur in the limestones of the Yoredales and in the Carboniferous limestone formation. The two formations have an aggregate thickness of about 740 feet and consist of seven principal beds of limestone, separated by layers of shale and sandstone. In Furness, where the deposits are all in the carboniferous limestone, the formation is over 950 feet thick. The dip is westward in Cumberland. In Furness it is S.E., S. and S.W. The orebodies occur, at one place or another, in all the seven limestones of the Cleator district, as may be seen with regard to all except the bottom limestone by an inspection of Figs. 54 and 56. In Furness there are not the same means of fixing the position of the deposits vertically owing to the great thickness of limestone in one mass, but we know that some of the deposits at Lindal Moor are near the base of the formation, whilst others, as at Stank, are immediately below the Yoredale shales.

The orebodies occur alongside faults of pre-Permian or early Permian age. Most of them in the Cleator district bear about 40° N.W. and S.E. and dip towards the N.E. Others have a direction about 48° N.E. and S.W. and dip northwestward. The former intersect the latter, and have had one or more differential movements in post-Permian times (see Fig. 56). The throw of some of the faults is large. That alongside the deposit worked by No. 1 pit, Montreal, has a throw of about 1,400 feet. The Salter-Winder Gill fault has a throw of about 540 feet at Winder Gill; that at Wyndham Pit, Bigrigg (see Fig. 54), about 100 feet.

Some of the deposits in Furness are alongside faults bearing 42° N.W. and S.E.; others by faults which bear 82° N.W. and S.E.

The flat deposits, by the side of the N.W. and S.E. faults in the Cleator district, are nearly always in the beds to the rise of the faults, like those seen on the east side of the fault in Fig. 57. Some are found on the dip side, but they never extend far from the fault. Fig. 55 is a cross-section of the deposits worked by Wyndham Pit, Bigrigg, and Fig. 56 a plan of some of the deposits, in the top limestone, of the same neighbourhood.

The orebodies follow in great measure the jointing of the limestone, as is the case in other districts and with other minerals, where the country rock is limestone. In a paper by J. D. Irving on "Replacement Orebodies,"[94] much stress is laid on the function of multiple fissuring in the formation of orebodies having the irregular form shown in Fig. 55, each fissure being supposed to extend downwards indefinitely and to act as a feeder, along which the mineral solutions gained access to the limestone. In the case shown in Fig. 55, I am satisfied the joints along which the ore in the first limestone formed do not extend below the bed of limestone. That rock is underlain by a bed of close-grained sandstone known as the 'Little Whirlstone,' below which a bed of shale—called the 'Little Sill'—occurs. There is no sign of the joints seen in the limestone extending into either of these beds, nor are they to be seen in the second limestone which underlies the Little Sill. Fig. 57 is a cross-section of the Winder Gill mine in the Frizington district. There, deposits were worked in the fifth and sixth limestones on the west side of the fault, and in the third and fourth limestones on the east side.

Fig. 58 is a cross-section of the Lindal Moor deposit in Furness, and Fig. 59 a cross-section of the Yarlside deposit in the same district.

A number of very important and interesting sections have been revealed in the working of these deposits. Some of them are given in Figs. 60, 61, and 62. The first was seen at Crossfield mines, the second at Eskett Park mines, both in Cumberland; the last is a vertical section exposed in the Askam mines, Furness.

These sections show thin layers of shale interbedded with the ore and limestone alike, and are an absolute proof of replacement.

[94] Trans. of Canadian Mining Inst., Vol. XIV.

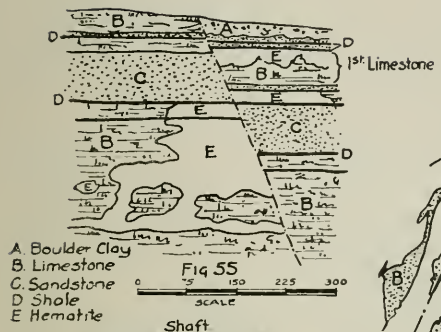


Fig 55

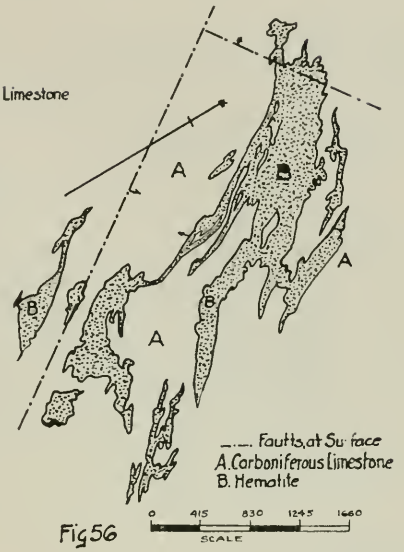


Fig 56

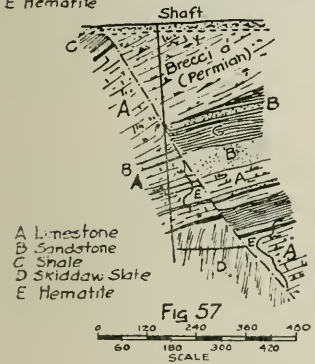


Fig 57

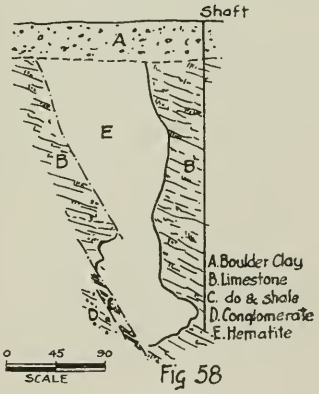


Fig 58

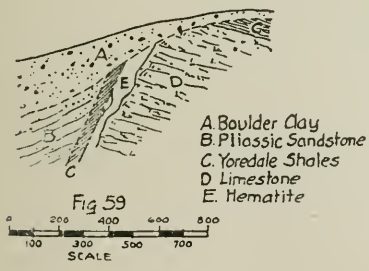


Fig 59

The area of some of the deposits is large, that at Parkside, in Cumberland, extending over 34 acres—all high-grade ore. The roof of the deposits in a number of cases is—like that at Eskett Park No. 5 Pit—soft shale, and the plane of contact between the ore and the shale is as regular as that between any

two beds of limestone. The Parkside deposit had a roof of millstone grit, and although the area of the deposit was very large, not a stone seemed to have moved. Had the ore been laid down in a cavern in either of these cases, the roof must inevitably have fallen.

The harder ore contains numerous 'loughs' or 'druses,' which are usually lined with 'kidney ore' and crystals of quartz, calcite, dolomite, arragonite, and specular iron ore. Occasionally crystals of fluorite, barite, pyrite, pyrolusite, and hausmannite are met with. In some cases the ore in the walls of the loughs is laminated for two or three inches. Occasionally ore in contact with the enclosing limestone, or with inclusions of that rock, is also similarly laminated. Much of the harder ore is seen, under the microscope, to contain numerous minute irregular cavities filled with quartz.

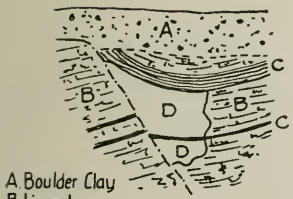
Contacts between ore and sandstone or shale are very definite, but between ore and limestone there is usually a gradation from one to the other.

Fossil bivalves and Nautili, similar to those occurring in the adjacent limestone, have been found in some of the orebodies converted into hematite, and I have seen crinoids for part of their length converted into ore, the other part being calcite.

Various pseudomorphs have been found in the loughs—hematite after crystals of calcite, fluorite, barite, and pyrite.

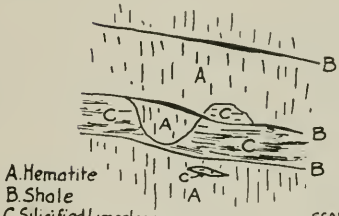
There is not any evidence of these ores being alteration products such as we find in the hematite of Somorrostro, Spain. There is neither siderite nor pyrite, except as crystals in the loughs and which are later formations. In some cases the limestone adjoining the ore is more or less saturated with silica.

The whole of these important deposits are found within three areas, the Cleator Moor district, the Millom district, and Furness. Each of these districts is on the flank of three separate areas of Skiddaw Slates, part of the Ordovician, the lowest known sedimentaries in this part of the country. They are evidently the centres of three probably contemporary, but separated, uplifts, which occurred in early Devonian times, for the Carboniferous rocks repose, at one part or another, on a plane of marine



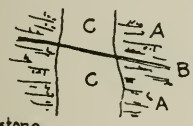
A. Boulder Clay
B Limestone
C. Shale
D. Hematite

Fig 60.



A. Hematite
B. Shale
C. Silicified Limestone

Fig 61.



A. Limestone
B. Shale
C. Hematite

Fig 62.

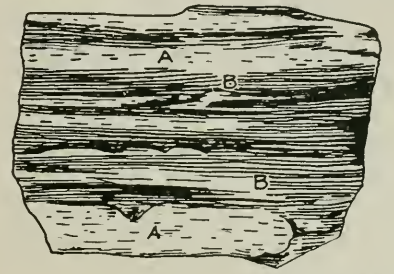


Fig 63
Full Size

A. Light grey rock
B. Dark brown do. ferruginous

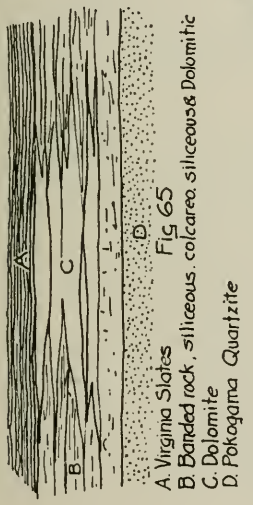
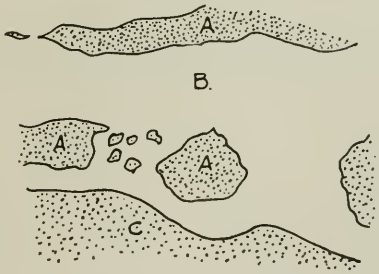


Fig 65

A. Virgina Slates
B. Banded rock, siliceous, calcareo, siliceous & Dolomitic
C. Dolomite
D. Pokogama Quartzite



A. Light Grey rock
B. Brown rock
C. Dark Brown Do highly ferruginous

Fig 64. About ½ size

denudation cut out of every member of the Ordovicians and Silurians. When the plutonic disturbances which took place at the close of the Carboniferous period set in, they would be much more likely to fault the Carboniferous rocks reposing directly on the Skiddaw slates than those resting on higher formations; and further, the metallic vapours would be more likely to reach

the Carboniferous rocks where they lay on the lower Ordovicians than when on the upper rocks of that system or on lower Silurians.

Fragments of hematite occur in the Middle Permian breccia, showing that the ore is older than a great part of the Permians.

Some of the foregoing facts insist upon metasomatic replacement for an explanation of the orebodies. In no other way could the shale roofs and partings have remained as they are now found. The occurrence of a fault of large throw in connection with each deposit affords a suitable way by which the iron vapours and solutions could rise from below. The source of the ore cannot be the adjacent Carboniferous rocks. The limestone near the deposits is often stained red by hematite, but farther off it does not contain a trace of iron. Nor can the deposits have been formed by infiltrations from Triassic rocks as some writers have thought, for the ore is of pre-Permian or early Permian age. There are not any volcanic rocks in either district from which the ore could have been derived.

The Iron Ores of the Mesabi Range, Minnesota.[95]—These important deposits occur in the Biwabik formation of the Upper Huronian of the U.S. Geological Survey. The rock chiefly associated with the ore is known as 'Taconyte,' a name given to it by H. V. Winchell. It has a thickness ranging from 200 to 2,000 feet, being about 1,000 feet average, and where unweathered consists of a ground mass of silica, cryptocrystalline, chalcedonic or phenocrystalline, in which are thickly strewn rounded or subangular bodies that consist largely of a greenish silicate of iron, supposed by some writers to be glauconite. Rounded grains of calcite also occur. Mr. Spurr says these grains were "apparently originally detrital, and in some limited areas they increase in number till they form nearly the whole bulk of the rock." He gives the constitution of the green mineral, after making allowances for the presence of siderite in the sample analysed, as per table A on p. 417. The average of 27 samples of glauconite, according to Dana, is shown by table B.

[95]The Iron-Bearing Rocks of the Mesabi Range, by J. E. Spurr. Bulletin No. 10, Geol. and Nat. Hist. Survey of Minnesota.

	A per cent	B per cent
SiO_2	50.00	52.19
Al_2O_3	5.54	6.80
Fe_2O_3	8.05	6.83
FeO	26.56	15.70
CaO	2.59	.71
MgO	3.78	1.79
Na_2O	.45	.30
K_2O	.41	6.24
H_2O	2.54	8.45
	99.92	99.01

There is a very great difference in the potash in the two tables. Dana's highest in the 27 samples is 12.96 per cent, his lowest 3 per cent.

Everywhere the rock consists mainly of silica, alumina and one or more of the ores of iron, but there are considerable variations, some of which are due to weathering. These variations are shown by the following analytical results:—

	(1)	(2)	(3)	(4)
SiO_2	86.35	57.00	98.17	77.89
Al_2O_3	.78	1.43	.50	13.55
Fe_2O_3	7.41	11.08	1.03	1.83
FeO	3.46	27.05	..	..
CaO	.01	.40	Tr	Tr
MgO	.05	2.02	Tr	.36
Na_2O	.01	.397	.25	.58
K_2O	.12	.113	Tr	.84
H_2O	.01	..	..	4.45
CO_2	1.22	..	..	..
Loss on ignition	..	.91	.19	..
	99.42	100.4	100.14	99.50

(1) Under the microscope this specimen was found to consist of silica, siderite, magnetite, and hematite.

(2) Cryptocrystalline silica spotted with granules of green silicate of iron, magnetite, etc.

(3) Fine grained siliceous powder.

(4) Consolidated fine white powder with frequent bands of brown or light red.

In places the rock is banded—layers of iron ore, more or less pure and of varying width alternating with and merging into the layers of siliceous material, as shown in Fig. 63. These bands may often be found of every size upwards, till the body of iron ore becomes large enough to merit the name of an ore-deposit.

In other parts the rock presents a more or less mottled appearance, as in Fig. 64.

The taconyte is overlain by the Virginia slates, and underlain by the Pokegama quartzite, the three formations being named by Spurr the Animikie Series. The base of the slates is calcareous, and becomes in places an impure limestone, often dolomitic or impregnated with siderite or other ore of iron.

The rocks for a great part of the Range are tilted to a gentle monocline, from nearly horizontal to about 30 degrees towards the southeast. At the Virginia Salient the dip is partly west and partly south. This tilting probably took place at the close of the Keweenawan. The series is intersected by faults both normal and reverse; it is also folded east of the Virginia Salient, but when these faults and folds took place is not clear. From the time of this uplift to the dawn of the Cretaceous the rocks appear to have been exposed to continuous denudation. There are a few small patches of conglomerates and shales, belonging to the Cretaceous, resting on the iron-bearing rocks that afford evidence of the first subsequent submergence. The conglomerates consist mainly of fragments of the underlying rock. Mr. Spurr says "that at the time of the formation of the conglomerate there existed hard iron ore in the iron-bearing member."

The ore-deposits occur as irregular bodies in the taconyte; frequently they rest on the underlying quartzite. At other

places they do not extend so far down in the ore-bearing formation. They frequently attain 200 or 300 feet in depth, but rarely more than 350 feet. Their horizontal dimensions in some cases are enormous. The length of one deposit was 2½ miles, and its breadth ¾ of a mile—probably the largest body of high-grade ore known. The length of the orebodies is, in some cases, coincident with the strike of the enclosing rocks; in other cases at right angles thereto. The contact of the ore and taconyte is extremely irregular, tongues of ore extending into taconyte, and tongues of taconyte projecting into the ore. In many places 'horses' of taconyte occur completely surrounded by ore. There is a gradual transition from the ore to the surrounding rock, in which the iron becomes successively lower and silica higher. Mr. H. V. Winchell[96] says, "The bedding planes of the original strata are perfectly preserved in the ore." Mr. Spurr[97] says, "The often well-developed bedded or laminated appearance of the ore-deposits has nothing to do with stratification." It is, however, a fact that the tongues of ore and taconyte, as well as the banding shown in Fig. 64, are parallel to the upper and under surfaces of the ore-bearing bed. The uppermost part of the shallower orebodies is frequently gothite; the lower part is often a red hydrated oxide; the middle and most valuable portion being bluish hematite. The deposits seem to be always in faulted ground, or where the rocks have been fractured and otherwise disturbed, as at the anticlinal and synclinal axes of the folds.

Mr. Spurr assumes the original ore-bearing rock to have consisted chiefly of silica with some alumina, and a quantity of silicate of iron which gave the rock a greenish hue. The orebodies he considers were formed by a concentration and alteration of this green silicate. There can be no doubt that there has been some alteration and concentration of the iron in the ore-bearing rock, just as we see it in the Northampton and Lincolnshire ores, but there is no evidence that the rock ever contained sufficient iron to produce the enormous deposits that have been found in it. Further, there is the difficulty of a direct metasomatic replace-

[96]The Mesabi Iron Range, Trans. American Inst. of M.E.'s, 1892.
[97]The Iron-Bearing Rocks of the Mesabi Range.

ment of the silica. I do not know of any pseudomorph after silica, but there are many after calcite.

I am disposed to think that the ore-bands of the taconyte as well as the large orebodies, were preceded by bands and coalescing lenses of limestone deposited alternately with the accompanying siliceous material. Fig. 65 illustrates this suggestion.

The banded taconyte is similar to the itabirite in which the splendid deposits of hematite occur in Minas Geraes, Brazil, and both probably originated in the same way. The limestone was probably replaced by carbonate of iron and afterwards altered to gothite, limonite, and hematite—the iron solution travelling upward along the faults. Mr. Spurr thinks, from his miscroscopic observations, that the iron oxides—magnetite and hematite—preceded the siderite, because he had found in some of his slides magnetite encircled by siderite, but precedence cannot be determined in that way, because the alteration of siderite into magnetite may proceed along joints in such a way that a slice of rock cut in a particular direction would show the magnetite to be entirely surrounded by siderite, whilst a section at right angles might show that it was only a needle of magnetite projecting into the siderite.

The green silicate might come into existence by the action of the bicarbonate of iron on the silicate of potash. Analyses of the rock now do not find much potash, but that is to be expected if this suggestion is a correct indication of what took place.

A question which arises in connection with the above replacement suggestion is—why should faults, anticlinal ridges and synclinal troughs occur where the large deposits of lime were formed ? The answer, I think, is that the limestone would be much more likely to be fractured, and to yield to both the tensile and compressive strains to which the rocks were subjected, than the quartz rock.

MISCELLANEOUS REMARKS

Further illustrations might have been given, as, for example, of the copper deposits in the Carboniferous limestone of Arizona and of lead and zinc deposits in Missouri, but they would not

add anything to the argument. They would simply expand and vary the evidence. In my study of this complicated subject it has been repeatedly borne in upon me that there is a great want of exact information relating to the vaporization of metallic compounds, and to the action of mineral-bearing solutions under conditions approximating those existing in the water-bearing zone. The effect on the vaporized minerals in their passage through the rocks between the barysphere and the water-bearing zone needs elucidation by experiment. The direct substitution of silica by other minerals requires demonstration. The solution of minerals and their re-deposition, in masses and as crystals, call for further work. When these problems have been carefully worked out, I think we shall be in a much better position than we are at present to speak with confidence on the formation of orebodies.

In conclusion, I would like to express my appreciation of the work done by the United States Geological Survey in this connection, as well as in working out the principal features of a large number of orebodies, which is so much in advance of the work done by the Geological Survey of Great Britain. In the latter country important mineral-bearing districts with great potentialities have received the most perfunctory attention. Maps that are glaringly wrong and incomplete have been issued to the public for years, notwithstanding that their inaccuracies were long ago brought to the notice of the office responsible for their production and publication. We hear a great deal now-a-days in England about "reorganization after the war"; no doubt much work of that kind needs to be done in various directions, but nowhere more than in the Government Geological Survey work. The nation will benefit enormously when proper attention is given to our mineral deposits by a body of trained men who can obtain access to mines generally, and the plans, sections, and other data relating to the working thereof, and afterwards show on their maps the geological features that may serve as a reliable guide to further explorations.

THE MESOZOIC PERIOD OF MINERALIZATION IN BRITISH COLUMBIA*

By Stuart J. Schofield

The preliminary estimate by Mr. W. F. Robertson of the metal production for 1917, excluding that of placer gold, of British Columbia is $27,113,786. An analysis of this production brings out the fact that it has been won mainly from deposits genetically associated with batholithic intrusives of Mesozoic age. This fact should have a direct bearing on the future search for ores in British Columbia.

On the accompanying map, the rocks are grouped as follows: (1) Pre-Cambrian, (2) Palæozoic and Triassic, (3) Mesozoic, and (5) Tertiary. The Triassic is grouped with the Palæozoic since the deposition of the Triassic sediments took place before the intrusions of the Mesozoic granodiorite, and hence was affected by it.

The following is the table of formations:

Pleistocene.—Glacial deposits.

Tertiary.—Mostly lava flows, rhyolites, andesites, basalts, and tuffs; some sedimentaries, sandstones, shales, conglomerates, and coal. Kamloops, Tulameen, Similkameen, etc., coal areas.

Mesozoic.—Mostly sedimentaries, sandstones, shales, conglomerates, and coal measures. Nanaimo, Graham Island, Peace River, Crowsnest Pass, Flathead River, Groundhog coal areas. Batholithic intrusives. Coast Range batholith, Nelson granite of Nelson, Ymir, Ainsworth, Slocan, and Franklin, Kootenay granite of East Kootenay, the Trail granodiorite and monzonite of Rossland, the granodiorite of the boundary district (Phoenix camp, Sunset, and Motherlode mines), West Kettle batholith of Beaverdell map-area.

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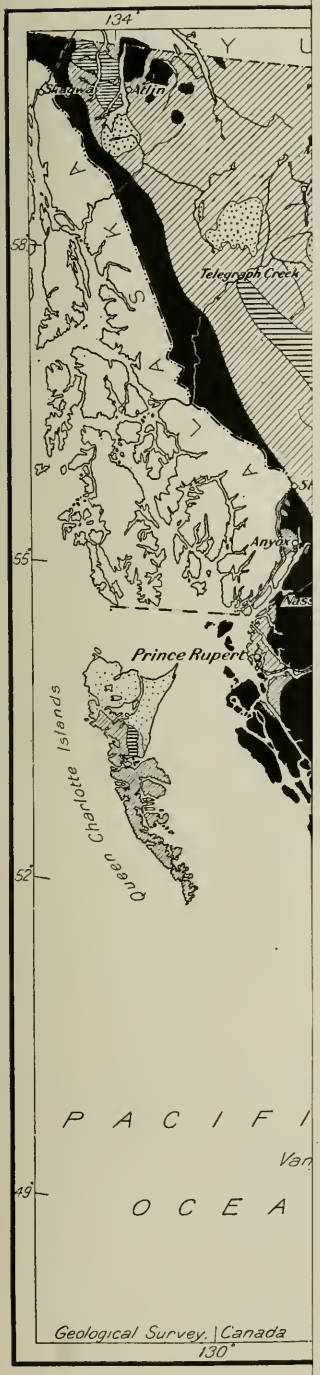
134°
Y
U
Telegraph Creek
58°
55°
Prince Rupert
Queen Charlotte Islands
52°
P A C I F I
O C E A
49°
Geological Survey. | Canada
130°

Diagram showing the geology of
BRITISH COLUMBIA
Scale
Miles
25 0 25 50 75 100 125 150
(Compiled by S. J. Schofield)
LEGEND
Tertiary
Volcanic and sedimentary rocks
Mesozoic
Sedimentary rocks
Batholithic intrusions
Triassic and Palaeozoic
Sedimentary and volcanic rocks
Pre-Cambrian
Mainly sedimentary rocks
YUKON
NW TERRITORIES
ALASKA
PACIFIC
OCEAN
Vancouver Island
Queen Charlotte Islands
UNITED STATES
Prince Rupert
Stewart
Telegraph Creek
Hazelton
Telkwa
Kitimat
Fort Grahame
Fort St John
Hudson's Hope
Bulkley House
Germansen
Fort St James
Ft Fraser
Fort George
Quesnel
Barkerville
Tete Jaune Cache
Jasper House
Edmonton
Soda Creek
Coola
Quatsino
Clayoquot
Victoria
Revelstoke
Sicamous
Vernon
Kaslo
Cranbrook
Golden
Banff
Calgary
Geological Survey, Canada

Palæozoic and Triassic.—Sedimentaries and volcanic rocks; Nicola series; Cache Creek series; Slocan series; Ainsworth series; Pend-d'Oreille schists and limestones, etc.

Pre-Cambrian.—Purcell series; Summit series; Selkirk series; all characterized by the predominance of quartzites with subsidiary amounts of limestones. Shuswap series, schists, gneisses, and some limestones.

An examination of the accompanying map will show the distribution of the various areas. It will be noticed that the general trend of the groups is northwest-southeast with the oldest rocks forming an axis of elongated masses from the Boundary line through the Shuswap lakes to Alaska. These old rocks are flanked on both sides by younger rocks which, broadly speaking, are found to be progressively later in age as we go eastwards and westwards of the axis.

On the eastern side of the axis, the sedimentary rocks form practically a conformable series from the Pre-Cambrian (Beltian) to the Cretaceous with an aggregate thickness of over 50,000 feet. The sediments of the Rocky Mountains were subjected to mountain-building forces only at the close of the Cretaceous. They were not disturbed by the early Mesozoic orogenic movements, and hence not by the intrusion of the Mesozoic granites and granodiorites. This explains the absence of ore deposits in these rocks. There is no evidence that they were intruded by batholiths of granite at the close of the Cretaceous, but, if such an intrusion took place, the batholiths are buried far beneath the present surface.

On the western side of the axis, the oldest formations yet recorded in British Columbia are the late Palæozoic series (Cache Creek series, the Slocan series, etc.), consisting of sediments and volcanic rocks of considerable thickness. These rocks suffered the effect of mountain building during the early Mesozoic, which was the first well-defined orogenic period in British Columbia. This movement, the most important event economically in the geologic history of British Columbia, was accompanied by the intrusion of vast quantities of granite and granodiorite. These

intrusions, especially in their cooling stages, were characterized by the escape of mineral-bearing solutions which penetrated the surrounding intruded rocks and formed various types of ore deposits. By examining the map it will be seen that the mineral-bearing areas are associated with the areas of intrusion, either in the intrusion itself, as at the Molly Gibson mine of West Kootenay, or close to the contacts of such intrusions, as in the case of most of the deposits in British Columbia. Future explorations for mineral-bearing rocks of British Columbia should be guided by this fact, and the area of sedimentary rocks close to the granite masses, or in the granite masses themselves as inclusions or roof pendants, should be prospected thoroughly.

Following the intrusion of the Mesozoic granite masses, the greater part of British Columbia, except the area now occupied by the Rocky Mountain system, was subjected to erosion, and the products of this erosion are now seen in the Cretaceous and later rocks of British Columbia. These rocks consist mainly of sandstones and shales with minor beds of conglomerate and seams of coal.

The Tertiary history of British Columbia is rather complex, but its main feature was the great outflow of volcanic rocks upon the surface. Sedimentation and erosion were also prominent. Economically, these rocks are of minor importance in so far as metallic deposits are concerned, but are of considerable importance on account of their association with beds of coal, clay, and other non-metallic deposits.

The Pleistocene was a period of glaciation and erosion during which time any oxidized portions of the Mesozoic ore deposits, with their accompanying secondary enrichments, were worn away. Most of the ore deposits of British Columbia, therefore, as they are found to-day, are primary in character; and, in contra-distinction to the deposits in the same geological province to the south, show very little evidence of secondary enrichment.

The following is a table showing the principal ore deposits of British Columbia:

District	Ores	Gangues	Intruded Rock	Intrusive	Age of Mineralization
Anyox	Pyrite, pyrrhotite, chalcopyrite	Quartz, calcite	Argillaceous limestones, tuffs, schists (palæozoic)	Granite	Mesozoic (jurassic)
Britannia	Pyrite, chalcopyrite, zinc-blende	Quartz	Slate, diorite porphyry, chlorite schist (palæozoic)	Granite	Mesozoic (jurassic)
Texada Island	Chalcopyrite, bornite, molybdenite, native silver	Garnet, diopside, Tremolite, epidote, calcite	Palæozoic limestone (pure)	Diorite, porphyrite dykes, and stocks of quartz diorite	Mesozoic (late jurassic)
Silver Standard (Hazelton)	Galena, zinc-blende, tetrahedrite, some chalcopyrite, arsenopyrite, and pyrrhotite	Quartz, siderite	Tuffs, Hazelton series (early Mesozoic)	Granodiorite	Mesozoic
Rocher Deboule (Hazelton)	Chalcopyrite, some galena, zinc-blende, tetrahedrite	Quartz or actinolite	Granodiorite (Mesozoic)	Granodiorite	Mesozoic
Hedley	Arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, pyrite	Calcite, garnet, epidote, pyroxene, quartz, amphibole	Banded and impure palæozoic limestone	Diorite-gabbro	Early mesozoic (jurassic)
Tulameen Lillooet	Chromite containing microscopic diamonds	Serpentine, olivine, asbestos	Cadwallader series (triassic)	Peridotite sill	Mesozoic (jurassic)
Lillooet	Free gold, pyrite, arsenopyrite	Ribboned quartz	Cadwallader series (triassic)	Augite diorite, and granodiorite	Mesozoic (late jurassic)

District	Ores	Gangues	Intruded Rock	Intrusive	Age of Mineralization
Franklin	Pyrite, chalcopyrite, sphalerite, galena, magnetite	Calcite, garnet, epidote, diopside, quartz	Palæozoic limestones	Granodiorite	Mesozoic (jurassic)
Phoenix and Deadwood	Chalcopyrite, magnetite, specularite, pyrite, rarely bornite, and sphalerite	Garnet, epidote, calcite, actinolite, chlorite	Upper palæozoic crystalline limestone	Granodiorite batholith	Mesozoic (late jurassic)
Rossland	Chalcopyrite, pyrrhotite, pyrite, with gold and silver values	Silicified and biotitized country rock, with chlorite, calcite, garnet and quartz	Augite porphyrite sills	Stocks and tongues of granodiorite and diorite porphyrite	Mesozoic (late jurassic)
Salmo	Molybdenite and molybdite	Pyrite, epidote, orthoclase, kaolin, quartz, mica	Pend-d'Oreille schists and limestone	Quartzose, biotite granite	Mesozoic (late jurassic)
Sheep Creek	Free gold, pyrite; and galena and blende at Ymir	Pyritic quartz (oxidized)	Summit series, quartzite. Pend-d'Oreille schists at Ymir	Nelson granite	Mesozoic (late jurassic)
Molly Gibson West Kootenay	Galena zinc-blende silver ores	Siderite quartz	Granite Mesozoic		Mesozoic
Slocan and Ymir	Galena, zinc-blende and pyrite	Quartz siderite	Slocan series. Pend-d'Oreille group	Nelson granite	Mesozoic (late jurassic)
Ainsworth, Slocan	Galena, sphalerite, pyrite, native silver and oxidized ores	Altered limestone, argillite or quartzite	Limestone, argillite and quartzite	Nelson granite	Mesozoic (late jurassic)
Sullivan Mine (East Kootenay)	Galena, zinc-blende, pyrite and pyrrhotite	Garnet, diopside, quartz	Quartzite, pre-Cambrian	Nelson granite	Mesozoic

The above table shows that, with very few exceptions, the age of mineralization in the most important ore deposits of British Columbia is Mesozoic. In the past the tendency has been to place the time of the intrusion of these Mesozoic batholiths at the close of the Jurassic, but it has now been demonstrated that these batholiths are composite, consisting of successive intrusions from the same magmatic reservoir. However, the greater part of the intrusion may have taken place at the close of the Jurassic, with minor intrusions penetrating the older masses during the later periods in the Mesozoic.

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